Food Security and Climate Change in Dry Areas

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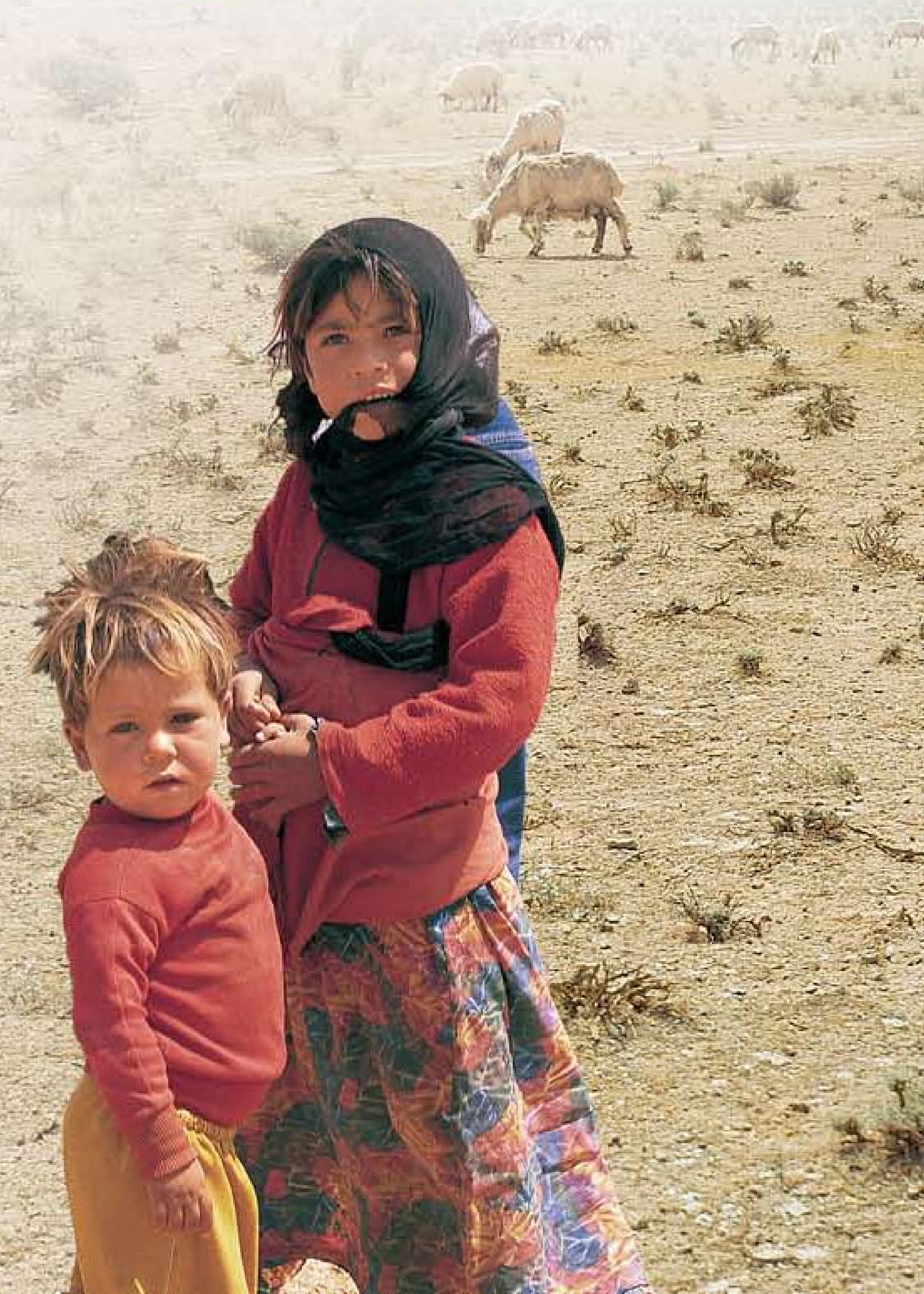

Conference Proceedings

International Center
for Agricultural Research
in the Dry Areas (ICARDA)

P.O. Box 5466, Aleppo, Syria

FOOD SECURITY AND CLIMATE CHANGE IN DRY AREAS

Proceedings of an International Conference
1-4 February 2010, Amman, Jordan

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International Center for Agricultural Research in the Dry Areas

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Theme 4: Mitigation, adaptation and ecosystem resilience strategies including natural resource management and crop improvement

Theme 5: Policy options and institutional setups to ensure enabling environments to cope with climate change impacts

Foreword

It is now generally recognized that climate change will have major impacts on agriculture and food security. Many parts of the world will be affected, but the challenges are greatest for dry areas, particularly in the developing world, where food insecurity is already a major concern. These areas have been the primary focus of ICARDA's work for more than three decades. The Center and its partners have developed a range of technologies to improve food security and environmental sustainability in areas of high climatic variability that are highly vulnerable to climate change. Together, we have made considerable progress – but much more remains to be done. For these reasons ICARDA took the initiative to organize an *International Conference on Food Security and Climate Change in Dry Areas*, which was held in Amman, Jordan, on 1-3 February 2010.

The Conference brought together leading experts in agriculture – more than 200 researchers, development specialists and policy makers from 29 countries – to address these challenges. It was supported by a range of partners including the host country, the Hashemite Kingdom of Jordan; national and international research centers; global and regional fora, including GFAR, AARINENA, APAARI and CACAARI; international development agencies; and non-profit organizations. This reflects the seriousness of the climate change threat, but also shows that many different organizations are prepared to work together to find solutions.

The objectives of the Conference were to share research results, synthesize the current state of knowledge, identify future priorities, and finally to create a network of partners to implement a comprehensive action plan to minimize the impacts of climate change on food security in dry areas. The Conference culminated in the Amman Declaration, in which all participating organizations pledged to take a series of measures to respond to climate change.

The papers presented at the Conference are published in two companion volumes: a book of abstracts, which has already been published, and this volume containing the full papers. The papers cover a wide range of topics. Plenary presentations and selected case studies provide a broad overview. These are followed by papers grouped under five themes: current status of climate change; impacts on natural resources and agricultural production systems; impacts on food security, livelihoods and poverty; mitigation and adaptation strategies; and policy and institutional options to cope with climate change.

We would like to acknowledge here the valuable financial support provided by the OPEC Fund for International Development; FAO; the International Development Research Center; the Middle East Science Fund, King Abdullah II Fund for Development, and the Scientific Research Support Fund of the Ministry of Higher Education and Scientific Research, Jordan; and Bioversity International.

These Proceedings, which synthesize the experiences of a large number of experts from different fields, will be useful to researchers, development planners, aid agencies and policy makers who are interested in sustainable agricultural development in a changing climate.

Mahmoud Solh
Director General
ICARDA

Introduction

The dry areas of the developing world occupy some 3 billion hectares, and are home to one-third of the global population. About 16% of the population lives in chronic poverty, particularly in marginalized rainfed areas. Characterized by water scarcity, the dry areas are also challenged by rapid population growth, frequent droughts, high climatic variability, land degradation and desertification, and widespread poverty. Poverty and other social problems are leading to unsustainable agriculture, degradation of natural resources and increased migration. Another major challenge is the impact of globalization, due to the changes in the world trade system and potential competition. This instability is further exacerbated by unrest in the financial markets. Food insecurity, poverty, and poor access to natural resources also manifest themselves in conflicts. Conflicts have been concentrated in regions heavily dependent on agriculture destroying food and water supply sources, biodiversity and seed systems, and resulting in long-term negative effects on the environment.

Global climate change is a serious threat to the environment, natural resource and production systems in dry areas. Current global median projections from the Inter-Governmental Panel on Climate Change (IPCC) predict an increase in mean temperature and a decrease in mean annual rainfall in many of the already marginal dry areas. Such changes will result in lower river flows, increased evapotranspiration, greater terminal heat stress, drier soils, and shorter growing seasons; all of which would decrease agricultural productivity. Climatologists also predict more frequent climatic extremes such as longer droughts, more intense storm events and even extreme low temperature spikes that will damage or destroy crops and vegetation that are not adapted to these stresses. Both coastal and inland salinization risks are likely to increase, with even age-old natural aquifers being contaminated. There is a real possibility that some areas will become uninhabitable, and that some low-lying fertile areas will go out of cultivation.

The Stern Report (The Economics of Climate Change, 2006), calls for immediate action against global climate change suggesting that the global economy will be reduced by 20% unless urgent action is taken. The threat to the dry areas is particularly acute and there is a desperate need to develop not only technical options, but also policy and institutional options that improve livelihoods and increase food security under changing climates.

To address these issues, the International Center for Agricultural Research in the Dry Areas (ICARDA) with the Jordan National Center for Agricultural Research and Extension (NCARE) and other national, regional and international partners organized the international conference on Food Security and Climate Change in Dry Areas, 1-4 February 2010, in Amman, Jordan.

The aims of the Conference were to: (a) share views and experiences between national and international experts and other stakeholders on the urgent food security issues expected to be impacted by climate change; (b) identify technologies, economic and policy options and priorities, to buffer climate change impacts through mitigation and adaptation and ecosystem resilience; (c) identify effective modalities and mechanisms of cooperative partnerships between various national, regional and international institutes and organizations; and (d) mobilize human and financial resources to enhance regional and international cooperation, and to support research and development activities to cope with climate change.

The Conference was inaugurated by H.E. Prime Minister of Jordan, Mr Samir Rifai. The guest-of-honor address was delivered by H.R.H. Prince El Hassan Bin Talal of Hashemite Kingdom of Jordan. The scientific program covered five themes through invited keynote presentations in plenary sessions, and contributed papers presented orally in concurrent sessions or displayed as posters. The themes included: 1. Current status of climate change in the dry areas: simulations and scenarios available; 2. Impacts of climate change on natural resource availability (especially water), agricultural production systems and environmental degradation in dry areas; 3. Impacts of climate change on food security, livelihoods and poverty; 4. Mitigation, adaptation and ecosystem resilience strategies including natural resource management and crop improvement; and 5. Policy options and institutional setups to ensure enabling environments to cope with climate change impacts.

A total of 50 presentations (13 keynote addresses and 37 contributed papers) were made by specialists in various fields covering different scientific disciplines including social studies. The recommendations emanating from the deliberations were discussed in a plenary panel discussion and consensus was reached on an **'Amman Declaration'.** The Declaration has been widely disseminated, and will contribute significantly to achieving the objectives of the Conference.

This volume contains most of the presentations and the Amman Declaration. It is hoped that it would prove useful to all those interested in the sustainability of agriculture, improving rural livelihoods, and protecting natural resources in dry areas in the face of changing climates.

Plenary Presentations

Ensuring food security in a changing climate: How can science and technology help?

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Abstract

Agriculture in dry areas faces severe challenges – both biophysical and socioeconomic. These challenges are expected to become even more severe as a result of climate change, leading to more food insecurity and poverty. Today, an estimated one billion people face hunger and absolute poverty. In many developing countries, the gap between food production and demand is increasing rapidly. The biophysical constraints to dry-area agriculture include acute water scarcity, frequent drought, salinity, desertification and other forms of land degradation, and new challenges such as changes in pest and disease distributions caused by climate change. The socioeconomic factors include high population growth, poverty, weak institutions and lack of enabling policies – all contributing to unsustainable resource use – as well as related issues such as unemployment and rural-to-urban migration. These challenges cannot be overcome without advanced technologies and innovative approaches, which require greater investment in agricultural research, and political commitment to strengthen policies and institutions.

ICARDA and its partners use a three-pronged approach, aiming to enhance adaptation, mitigation and ecosystem resilience. The role of science and technology is best illustrated through examples of successful technologies that have enhanced productivity in a changing environment. Improved varieties, developed through conventional as well as biotechnological methods, offer higher and more stable yields, resistance to multiple stresses, and the prospects of adequate food supplies even in poor seasons. Over 900 improved varieties, developed jointly by ICARDA and its partners, are grown worldwide, generating net benefits estimated at US $850 million per year. Ongoing efforts aim to apply biotechnological tools and recombinant DNA techniques to develop the 'next generation' of varieties with better adaptation to climate change. New technology packages such as drought-tolerant wheat and barley, winter chickpea and integrated pest management, have increased output and productivity and lowered production costs. Seed systems research has developed innovative models to disseminate new varieties tolerant to biotic and abiotic stresses. Modern scientific tools such as remote sensing and GIS are helping to refine and scale-out traditional technologies such as rainwater harvesting, and significantly increase water productivity. Conservation agriculture technologies are helping to increase yields while protecting soil resources. Intensification and diversification of production systems – for example, protected agriculture, introduction of high-value crops and value-added products – are creating new income and livelihood options. Rangeland and livestock research is helping to strengthen livestock production. Socioeconomics research (impact studies, poverty mapping, value chain analysis, etc.) are helping to target interventions effectively and increase the adoption and impact of research products.

Ultimately, progress in research and development requires partnerships. ICARDA's biggest strength lies in creating and facilitating partnerships between different institutions: national research systems, advanced research institutes, universities, NGOs, farmer groups, the private sector, regional and international development agencies, donors and others. These partnerships bring huge synergies that can provide sustainable solutions to the problems of hunger and poverty in the world's dry areas.

Keywords: climate change, partnerships, modern scientific tools, research achievements, science and technology.

Introduction

Countries with extensive dry areas face the threat of food insecurity due to the combination of limited natural resources, low agricultural productivity and rampant poverty. The food crisis of 2008, triggered by many factors including reduced availability of grains in global markets because of prolonged droughts in major exporting countries and diversion of land from food production to bio-fuels, exposed the vulnerability of the developing countries especially those relying on food imparts. It is now becoming evident that part of the problem being faced by the dryland areas could be attributed to the ongoing climate change.

Dry areas cover 41% of the earth's surface, and are home to over 2 billion people. Over 80% of the population here has to survive on an income less than US $ 2 per day - most of which is spent on food. Climate change will aggravate their plight unless governments in the region muster the political will to make the right investments and restructure policies to help communities cope with adversity.

While there is a wide diversity of agro-ecologies in dry areas, wheat and barley represent the main components of rainfed cropping systems, although such crops as sorghum, especially in Sudan, and cotton in Egypt and Syria (under irrigation), are also important. Faba bean, chickpea and lentil are important food legumes and a major source of protein in the daily diet of low-income people. Other crops, such as potatoes, summer crops, oilseeds and sugar beet are also important, especially where irrigation is available. Dryland fruit and vegetable crops such as olive, almond, fig, pistachio, apple, apricot, peach, hazelnut, grape, quince, date palm, cucumber, melon are an integral part of the farming systems as are the small ruminants (sheep and goats) raised on forage crops and rangelands. Raising small ruminants on pastures and rangelands is an important source of livelihoods particularly in low-rainfall areas and marginal lands.

Scarce water resources

Dry areas by definition are water scarce. The Middle East, North Africa and Sub-Saharan Africa are the world's most water-scarce regions and they are extracting water at a rate that is not sustainable. In some cases, such as Jordan, per capita availability of fresh water has already dropped to 170 m^3/year, well below the internationally recognized water scarcity standard of 500 m^3/year. Future projections of population growth indicate a further decrease in per capita water resources.

In the Middle East and North Africa, for example, current per capita renewable water resources (1100 m^3/year) are projected to drop to 550 m^3/year by 2050. This will trigger a higher water withdrawal rate with both ecological and human livelihood implications. Water scarcity and quality are potentially serious threats to food security and health in dry areas. There is a direct relationship between food and feed security and access to water. The proportion of the population without access to reliable, uncontaminated water is as high as 78%. Irrigation accounts for 80-90% of all water used in dry areas. However, increasing competition for water among various sectors will likely reduce the share for agriculture to about 50% by 2050.

Desertification

Desertification or land degradation is major global challenge to food security. The dry areas are particularly vulnerable to land degradation and desertification. The recent Millennium Ecosystems Assessment Report indicates that desertification threatens over 41% of the world's land area, mostly in the dry areas.

Climate change

The Inter-Governmental Panel on Climate Change reports suggest that West Asia, North Africa, and Sub-Saharan Africa will be most adversely affected by climate change. Depending on the model used, North Africa and West Asia are projected to see a 6.5 and 3% decrease in rainfed cereal production, respectively. However, North Africa, West Asia and Central Asia are projected to see a 6.5, 4.5 and 10% increase in irrigated cereal production, respectively. Again, depending on the model used 49% to 33% decrease in production from grasslands/scrubland and a 14-15% decrease in production from woodlands is projected for North Africa and West Asia respectively. The areas of cultivatable land are projected to decrease, which will further exacerbate food insecurity.

Climate change is already severely affecting the dry areas. Crops and livestock are facing more extreme temperatures and drought events. ICARDA, through its focus on dry areas, is developing technologies that are helping farmers to cope with climate variability and change through adaptation, mitigation and greater resilience of production systems. The Center and its partners are developing crop varieties and production technologies to cope with the threats of drought, heat stress and other climate change implications. There is also need for technologies to improve water productivity, halt land degradation and combat desertification, e.g. soil and water conservation and better rangeland management practices. The approach must include community-based co-management of scarce natural resources and allow land users to link with research institutions and policy makers. It is much more cost effective to prevent land degradation and desertification, than to reverse degradation once it has occurred. This is true irrespective of the causes of degradation (overgrazing, erosion, salinization etc).

Food insecurity: prices, trade and self sufficiency versus self reliance

The West Asia and North Africa (WANA) region has changed from a net food exporter in the first half of the last century to the largest food importer in the developing world and will continue to be the largest cereal importer in the world in the foreseeable future, although the projected trends for Sub-Saharan Africa are also alarming. Demand for animal feed also exceeds the region's current production levels. Such shortages, coupled with water shortages and threats of diseases, are leading to low productivity and poor reproductive performance of livestock. The combination of increasing demand for food and limited land resources has a potentially negative impact on the overall food security situation.

In an increasingly globalized world it makes more economic sense for a nation to buy food instead of growing it. Whether or not the current situation subsides and market forces correct themselves, the crisis has alerted people to the global food issue and is forcing nations to consider their own food security. Food prices in recent times have been rising very sharply for various reasons. Whatever be the reason, higher food prices will directly affect the poor. It is projected that the dry areas will be most disadvantaged because of the increase in the cost of importing more food. Agricultural research is one of the few ways that will permit countries to become self sufficient, as was achieved by Syria, Iran and Uzbekistan.

Hunger and poverty are widespread. About 360 million people or 16% of the total population in the non-tropical dry areas of developing countries lives on less than one US dollar a day. Women and children are affected most. However, there are clear pathways out of the poverty trap and natural resource degradation because the dry areas have some specific advantages, such as plentiful sunshine, a long growing season, and warm temperatures; and with good investment in research and efficient management of natural resources, dry areas can be highly productive.

Food security: What can make the difference?

There are several key factors that need attention to enable dry area countries to enhance their food security. Some of the important ones are listed below:

- Enabling policy and political will;
- Advances in science and technology (S&T);
- Sustainable intensification of production systems;
- Integrated approaches and better NRM for economic growth;
- Sustainable intensification of production systems;
- Public awareness of the long term benefits of conservation technologies;
- Capacity development and institutional support; and
- Partnerships.

Policies: Dry area countries are characterized by marginal production resources and very high population growth rates (2.5%). With over 30% of their work force engaged in agriculture, they rely heavily on agriculture to address major economic development problems. They are marked by food insecurity, high unemployment, rural to urban migration, and migration to better endowed areas. In most developing countries, agricultural policies are inadequate to resolve these problems. Prevailing policies do not permit: (a) sufficient investment in research to make advances in science and technology; (b) sufficient monitoring and research impact assessment; (c) special attention to less endowed agro-ecologies; (d) sufficient incentives to research staff in certain countries and (e) support for regional and international cooperation.

Advances in S&T: Several advances in S&T are important to achieve food security. Among these, biotechnological tools will be very important in solving the food crisis although the cost of the technology will be high. The countries in the Near East lag far behind others in the use of biotechnological tools in developing improved crop cultivars and animal resources. Geographic Information System (GIS) is an important tool that has helped advance our understanding of the world by allowing us to focus on the power of maps and geography. Through national poverty maps, for example, social scientists are better able to focus on areas where poverty exists, which are likely to be first affected by additional problems such as drought and food price increases.

Expert Systems – computer programs that simulate the judgment and behavior of human authorities or organizations that have expert knowledge and experience in a particular field – are other technological tools of immense value for helping improve agriculture production. Agricultural Expert Systems are specifically developed for certain crops or commodities or practices to aid extension staff and farmers apply best practices in each field. ICARDA in cooperation with the Central Laboratory for Agricultural Expert Systems (CLAES) in Egypt has developed several expert systems. For example, NEPER expert system provides expert advice on wheat. It suggests integrated schedule for irrigation and fertilization using a crop model, and provides advice on seed selection, tillage, seed depth and density, pesticides and other factors. It diagnoses weeds that grow with wheat and provides advice on weed control. Diagnosis and treatment of 38 disorders afflicting wheat is covered.

Integrated approach for sustainable agricultural development: Improving food security and livelihoods of the resource poor in the dry areas requires an integrated approach based on the three pillars of sustainable agriculture: crop and livestock improvement, natural resource management, and development of policies and institutional capacity. Technology options for crop / livestock improvement and natural resource management are available. But for these technologies to make a positive impact, supportive policies and effective technology transfer are needed, which in turn would require stronger institutions. Policy makers must provide incentives to encourage farmers to invest in new technologies. Simultaneously, they must ensure long-term investment in research to maintain a flow of new technologies.

ICARDA's research for sustainable agriculture in dry areas

During the past three decades ICARDA's research portfolio has been changing based on emerging priorities and challenges. In ICARDA's new Strategic Plan for 2007-2016, the research portfolio is designed to integrate research and training activities carried out at headquarters and in collaboration with national partners. These are complemented by participation in CGIAR Challenge Programs, System-wide Programs, Eco-regional Programs and global initiatives. Essentially, ICARDA's new portfolio is based on a wide range of partnerships and a holistic approach to solving problems. This portfolio is built on four major programs:

- Biodiversity and Integrated Gene Management
- Integrated Water and Land Management
- Diversification and Sustainable Intensification of Production Systems
- Social, Economic and Policy Research

Research outputs from the new portfolio seek to directly contribute to the national programs' agendas, the Millennium Development Goals 1, 7 and 8; and indirectly to five other MDGs as well as to the CGIAR System priorities.

ICARDA's global eco-regional mandate covers the countries with massive dry areas. Of these, 35 are located in the Central and West Asia and North Africa (CWANA) region, which represents more than 80% of the non-tropical dry areas. This is why ICARDA focuses on CWANA as the platform for most of its research and training activities to address the problems of non-tropical dry areas globally. It reaches other dry areas in the world from this platform.

Major research achievements

1. Biodiversity

ICARDA operates within four centers of origin and diversity of crop plants. Its germplasm collection focuses on landraces and wild relatives of its mandate crops – drawn from diverse eco-geographic origins. The gene bank holdings currently stand at 133,000 accessions, including landraces and wild relatives, from all over the world. Around 70% of the collection originates from CWANA.

Some of the world's most important crops were domesticated in the centers of origin within which ICARDA operates – thus there is tremendous diversity in the CWANA region both in cultivated landraces and wild species. Future collections will be based on gap analysis and targeting of valuable traits. Over 40,000 samples are distributed each year to co-operators throughout the world for use in crop improvement.

2. Crop improvement

Improved yield potential and adaptability: More than 900 improved cereal and legume varieties have been released by national programs in partnership with ICARDA, and adopted by farmers worldwide. As an example, over 80 improved wheat varieties have been released by the national program of Syria through joint research with ICARDA. They cover about 90% of total wheat area. Production of wheat in the country has increased almost four-fold since the 1970s, from about 1.2 million to 4.8 million tons, making it a wheat exporting country from its former status of an importer. This increase in production generates gains of over US$ 350 million per year. This has also helped in saving about 3.5 million hectares of land for other crops. Such partnerships have led to similar trends elsewhere: Iran and Uzbekistan have achieved self sufficiency in wheat production. Similarly, in faba bean, which is important in China, the Middle East, Ethiopia, Eritrea and parts of South America, new high-yielding varieties and better production practices have helped Egypt achieve self-sufficiency and strongly increased output in Sudan, Ethiopia and other countries.

Heat and drought tolerance: Several high-yielding wheat cultivars with tolerance to heat stress have been developed in Sudan. This has made wheat an attractive crop in the South of Khartoum where heat stress once prevented its cultivation. Heat tolerance is very important in the context of adaptation to climate change.

ICARDA has developed drought-tolerant lentil varieties, which have been widely adopted by farmers in Jordan, Libya and Syria because they give economic returns even in dry years. Genetic material from the Middle East and Argentina has been used by ICARDA to improve south Asian lines, and a number of new varieties have been released to farmers in Bangladesh, Nepal, India and Pakistan. The Kabuli chickpea 'Gokce', developed by ICARDA and Turkish national scientists, has withstood severe drought in Turkey and produced economic yields when most other crops failed in 2007. Gokce is grown on about 85% of the chickpea production areas (over 550,000 ha). With a yield advantage of 300 kg/ha over other varieties, and world prices over USD 1000/t, this represents an additional income of US$ 165 million for Turkish farmers in 2007 alone. Research is underway to identify the genes that confer drought tolerance, using DNA-micro-arrays, which permit analysis of genes during different growth stages.

Resistance or tolerance to diseases and insect pests: Stem, leaf and yellow rusts are the most devastating wheat diseases. Working with the national programs of Egypt, Ethiopia, Sudan and Yemen, we mapped the routes of spread of these diseases in the region. In the 1980s and 90s we also identified genes for resistance and developed varieties resistant to leaf and stem rust. Recently wheat has been threatened by a new race of stem rust named Ug99, which has the potential to devastate wheat crops globally and pose a real threat to food security. To combat this threat, ICARDA and CIMMYT launched the Borlaug Global Rust Initiative (BGRI) in September 2005. BGRI is a consortium, involving over 30 countries, for developing and deploying wheat varieties with stable resistance to Ug99 and other races. FAO has also become a partner. Major successes have been achieved in protecting wheat against the Sunn pest, using integrated pest management methods with a major biocontrol component. The use of natural enemies decreases the amount of pesticide in the environment and reduces costs of inputs needed to protect the crop. One of the biggest achievements in food legumes has been the development of faba bean cultivars with combined resistance to Ascochyta blight, rust and the parasitic weed *Orobanche crenata*. Incorporation of resistance to Ascochyta blight and tolerance of cold in chickpea has made winter sowing of crop possible in the region, permitting it to grow in areas that were too dry for its cultivation. In the face of climate change, the winter chickpea technology would be an interesting adaptation strategy.

Anti-nutritional factors: In times of drought and even of water-logging, grasspea (*Lathyrus* spp.) is the only legume crop to survive. Hence, it is an 'insurance crop' for the poor. However, it contains a neurotoxin (ODAP), which induces paralysis of the legs when the pulse is consumed exclusively as becomes unavoidable when drought or water-logging affect a region. In collaboration with national partners, ICARDA has developed new, low-neurotoxin grasspea cultivars safe for human consumption. One such variety was released in Ethiopia last year. Given that grasspea breeding has not received the same resources as field pea and other grain legumes, more progress is anticipated in the future through conventional breeding and biotechnology.

3. Grain-for-Seed concept to cope with excessive drought

In a good season with no seed shortage about 75% of the seed required for planting comes from farmers themselves. In a bad season with excessive drought, severe seed shortage can occur. With advance planning and management it is possible to convert seed for grain to seed for planting. This can be used to maintain an adequate supply of certified seed with known varietal purity and performance.

4. Water management

ICARDA's water research focuses on sustainable increase of water productivity both at the farm and basin levels. The Center has launched a new water management project, involving 10 WANA countries. The goal is to promote community participation, efficient use of resources and expertise, and the use of technologies that increase water productivity. The project covers three major agro-ecosystems: the marginal rangelands or '*Badia*', rainfed system and irrigated system. This research has helped understand the drivers to increase water productivity at different scales:

- At the basin level: competition among uses (environment, agriculture, domestic), conflicts between countries, and equity issues
- At the national level: food security, availability of hard currency, and socio-political factors
- At the farm level: maximizing economic return, and nutrition in subsistence farming
- At the field level: maximizing biological output.

ICARDA has also been studying and promoting the use of alternative water resources. For example, marginal-quality water and treated wastewater have been found useful for growing cotton, forages and trees. Water Users' Associations have proved the best alternative for proper irrigation management at the river basin level. In Uzbekistan, studies have shown that conjunctive or blended use of drainage water with regular irrigation can optimize yield while conserving fresh water. One way of maintaining yields under variable rainfall in rainfed farming systems is to provide supplemental irrigation during periods of moisture stress. Research has shown that water use efficiency under supplemental irrigation is twice as high as in fully irrigated or rainfed regimes.

5. Integrated livestock/rangeland/crop production systems

A range of technologies have been developed to integrate crop-livestock-rangeland production systems. These include:

- Barley production with alley cropping of shrubs such as *Atriplex* spp.
- On-farm feed production
- Feed blocks produced from agro-industrial by-products
- Spineless cactus and fodder shrubs
- Flock management
- Natural pasture enhancement and rangeland management
- Increase animal productivity: animal health and nutrition, better use of genetic resources including wild breeds, and better access to markets and by-products
- Improvement of rangelands: rehabilitate degraded rangelands, improve grazing management.

Water productivity is a key issue in crop-livestock systems. Technologies have been developed to enhance feed water productivity, through feed selection, use of residues, feed water management and multiple use of water. Research covers water harvesting as well as watershed management, and builds on traditional systems such as the *tabia* and *jessour* system of Tunisia.

Similarly, research has focused on how best to modify traditional systems to reduce the pressure on rangelands. Options include:

- Barley/livestock systems
- Rangeland/livestock versus confined feeding.

6. Conservation Agriculture

Conservation agriculture is an important innovation for the fragile ecosystems of dry areas. Zero tillage, minimum tillage, and raised-bed planting have shown considerable promise in ICARDA's collaborative projects in Kazakhstan and now in West Asia.

7. Diversification and sustainable intensification of production systems

Diversification of agricultural systems and value-added products can greatly contribute to reducing risk and generating income, thus helping particularly small farmers to move from subsistence to sustainable livelihood. For example, indigenous fruits, such as olives, date palm, almonds, figs and pomegranate, are an important source of vitamins, protein and calories, especially for children and women, particularly in famine periods. Fitting targeted fruit trees and vegetable crops in the cropping systems can greatly help in improving livelihoods.

Protected agriculture provides multiple benefits of diversifying production and diets, generating income and improving water use efficiency. This has been tested and disseminated in several countries of the Arabian Peninsula, as well as in Afghanistan and Yemen. In Yemen, protected agriculture has made it possible to both conserve the terraces and increase farm income by diversifying into vegetable production under plastic houses erected using locally available material.

8. Socio-economic and policy research

The work is done using an integrated approach involving all the research programs. It focuses on analysis of poverty, livelihood strategies and gender. Impact assessment is used as one of the tools to measure the quality of research interventions and this is combined with studies of markets, policies, institutional needs. A key part of the approach is to include natural resource economics, which often means natural resource valuations. Success achieved from socio-economic and policy research includes:

- New methodology for poverty mapping - combines financial and environmental indicators
- Building impact assessment culture
- Frameworks and methodologies for assessing adoption and impact of technologies at various scales
- New approach to analyze on-farm water use efficiency
- Providing policy options to decision-makers in countries throughout dry areas to ensure sustainable use of natural resources

9. Capacity development

National agricultural research systems in the developing countries are often limited by a shortage of trained, skilled staff. ICARDA therefore places great emphasis on capacity building. We offer a range of opportunities: support for Masters or PhD degrees, short-term specialized courses, internships, collaborative projects, participation in research conferences etc. Over 600 postgraduate students, interns and research fellows have done theses research at ICARDA. Advanced institutions have co-supervised MSc and PhD students. To date, over 16,200 researchers, students and development workers have benefited from various types of non-degree training programs, in 825 group courses and individual training. The curricula for training courses are tailored to NARS' requests. The emphasis is on hands-on training that can be put to immediate use.

10. Community approach

ICARDA has always used a participatory, community-driven approach. An example of the community approach is typified by the Mashreq & Magreb (M&M) Project on 'Developing Sustainable Livelihoods of Agro-pastoral Communities of West Asia and North Africa'. This project comprises five separate projects/phases strung back-to-back since 1995 and funded by the International Fund for Agricultural Development (IFAD) and the Arab Fund for Economic and Social Development (AFESD). The project blended science and technology with socioeconomic studies to create a new paradigm of allowing community participation in the conduct of research and in developing action plans for development. This approach has expanded into participatory plant breeding and many other areas of ICARDA's current work.

Conclusions and future perspectives

Our common goal is to ensure food security in dry areas despite the various challenges including climate change, declining natural resources, population growth and others. It is widely accepted that intensification of production systems will have to be the primary means of increasing agricultural production. To achieve this objective, two areas are important: 1) Sustainable intensification through expansion of conservation technologies: good agricultural practices, sustainable water use and management, integrated production systems and diversification, integrated pest management, integrated plant nutrient system, no till/conservation agriculture, urban and peri-urban agriculture, organic agriculture. 2) Increasing productivity of marginal lands through the development of integrated livestock/rangeland/crop production systems.

Policy makers in dryland developing countries must consider several key factors:

- Food and feed insecurity are vital issues. Many poor countries have economies based on agriculture, yet many of these countries are net food importers,
- Rural poverty is widespread; the majority of poor are in rural areas. Widening income inequality and rises in food prices are matters of great concern,
- Natural resources are scarce, with significant degradation,
- Climate change implications – more drought and temperature extremes,
- The share of public spending allocated to agriculture is declining. This has had and will continue to have severe and long-term consequences,
- Public awareness of the long term benefits of conservation technologies are important and incentives should be provided to farming communities to demonstrate and realize these benefits for sustainable food security.

Changes in extreme climatic events and their management in India

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Abstract

Anthropogenic high production of green house gases and associated changes in climate are being looked upon as a great challenge to the food and livelihood security in India. Frequency and intensity of extreme chaotic and dramatic weather events like late/early onset of rains, late or early withdrawal, long dry spells, droughts, floods, cold/heat waves, cyclones, hailstorms, etc. have increased due to global warming. Himalayan glaciers are retreating at the rate of 12 to 24 m per annum and getting fragmented. About 28% of the geographical area of India is vulnerable to droughts, 12% to floods and 8% to cyclones. Weather extremes are highly unpredictable, damaging and difficult to manage as compared to gradual trends providing opportunities of adaptations in terms of alternative crops, varieties, farming, land use and livelihood systems. India has evolved appropriate policies, safety nets and institutions, enacted/amended laws, set up authorities and committed financial resources for immediate relief, adaptations and mitigation to reduce vulnerability to climatic changes. Medium and long term measures for in situ conservation of rainwater, new varieties/crops, diversification, developing and recharging of ground water, enhancing efficiency of surface water resources, breeding tolerant crops, trees and animals to offset vulnerability are in place. This paper illustrates how crop contingency plans, compensatory production systems, and safety nets have been used to manage chaotic climatic changes taking the case of 2009 drought. Safety nets like livestock, agroforestry, insurance, credit, employment, buffer food stocks, public distribution of food grains, fodder, feed and seed banks are described. Deployment of additional energy to extract ground water by the farmers was the latest unique feature of managing drought in India.

Keywords: adaptation and mitigation strategies, drought, extreme climatic events, food and livelihood security.

1. Introduction

Indian Meteorological Department has created a network of observatories for weather monitoring since 1877 and it is being updated with latest technology to record climatic changes and provide information to various stakeholders. Weather tracking systems have been further consolidated by automatic weather stations and satellite based observations. Private companies have been established that sell data to bankers, insurers and forward traders. Thus capability to forecast weather and climatic events has improved.

Observations indicate that Indian Himalayan glaciers are retreating at the rate of 12 to 24 m per year, a reflection of ongoing climate change. Reduction in the number of rainy days, and increased intensity and frequency of the extreme weather events in India during the past 15-20 years are observable manifestations of global warming (UNDP 2008). Climatic chaos like droughts, late/early arrival or withdrawal of rains, long dry spells, floods, cyclones, tsunami, cold/heat waves, hailstorms have been occurring frequently and have caused serious damage as shown in Table 1 (www.emdat.be 2009). During the period 1877 to 2009 India has witnessed 24 major droughts and the severest six occurred in 2002, 1987, 1972, 1918, 1899 and 1877 (Samra et al. 2002). On the long term average basis, it is estimated that about 57% of the geographical area of India is vulnerable to earthquakes, 28% to droughts, 12% to floods and 8% to cyclones.

Food, feed and livelihood security is very sensitive to the unpredictable chaotic and extreme weather events and therefore appropriate management of these events is of supreme national interest. Adjustment to gradually occurring climatic changes through various coping mechanisms of evolution, adaptation, resilience, reducing vulnerability, mitigations and safety nets is possible but for abrupt extreme events it is difficult. Although the food grain production in India in the last

Table 1. Average impact of climatic disasters in India from 1900 – 2000

Rank	Events	No. of events	Persons killed	Persons affected	Damage (million US$)
1	Drought	13	326,948	81,680,077	188
2	Flood	223	254	2,932,808	94
3	Tsunami	1	16,389	654,512	1,023
4	Cold Wave	22	212	na	6
5	Heat Wave	22	392	na	18
6	Storm	145	630	355,787	71

na: data not available, Source: www.emdat.be

two decades has shown a linear increase, the dip in production due to weather abnormalities or extremes in different years is a matter of great concern as it compromises the robustness of food security systems (Fig.1).

The Bundelkhand region of Central India, which used to have droughts once in 16 years in the 18th and 19th centuries, faced droughts three times as frequently in the period 1968-1992. The region has remained severely deficient in rains from 2005 to 2009 (NRAA 2008). Droughts in areas where floods frequently occurred in the past, and floods in areas which were known for high probability of drought, have been witnessed in the year 2009 (NRAA 2009). For example, in 2009, the region of Saurashtra (Gujarat), which is known for frequent droughts, witnessed widespread floods (NRAA 2009); while the Krishna basin of South India experienced lack of rain and drought in the main rainy season (July to September) but got 400 mm rain in three days in the end of the season (first week of October 2009) causing widespread flooding.

Mitigation of climatic changes is a long drawn process necessitating inter-sectoral and international cooperation. India has launched eight activity missions for mitigating climate change and one of them is dedicated to sustainable agriculture. Other missions on Water, Hills and Mountains also include agriculture and food-security related activities. Climate change program is intensively monitored by an adviser based in Prime Minister's Office. Research for developing new technologies to adapt to climatic changes has considerable gestation period. Some 200 research institutions and agencies such as the Indian Council of Agricultural Research, and Agricultural Universities have been mandated to undertake research. There is a host of institutions, innovative policies, programs, governance systems and budgetary provisions for climate-related research and disaster management (NDMA 2009). Ministry of Agriculture, Government of India is overall responsible for managing droughts, hailstorms, pests and disease epidemics. Floods, and geological, chemical, biological and nuclear related disasters are the responsibilities of other ministries.

In federal India, managing droughts and other calamities is mainly the responsibility of the State governments, whereas the Federal Government provides advisory and monetary support. A Calamity Relief Fund (CRF), authorized by the Finance Commission of India and reviewed every five years, remains with the districts – the basic administrative units of the States - for providing immediate relief and the amount spent is reimbursed by the Central Government later on. There is also a National Calamity Contingency Fund (NCCF) and the States can request the Federal Government to provide support from this fund in case of a disaster or calamity, based on claim filed by them that has to be authenticated by a Central Government team.

2. Predictions and forecasting of extreme events

This is a crucial component of the entire safety net from the preparedness point of view. Indian Institutes of Technology, ISRO, universities, Indian Meteorological Department (IMD) and others are engaged in modeling, data crunching, prediction and forewarning about extreme weather events for

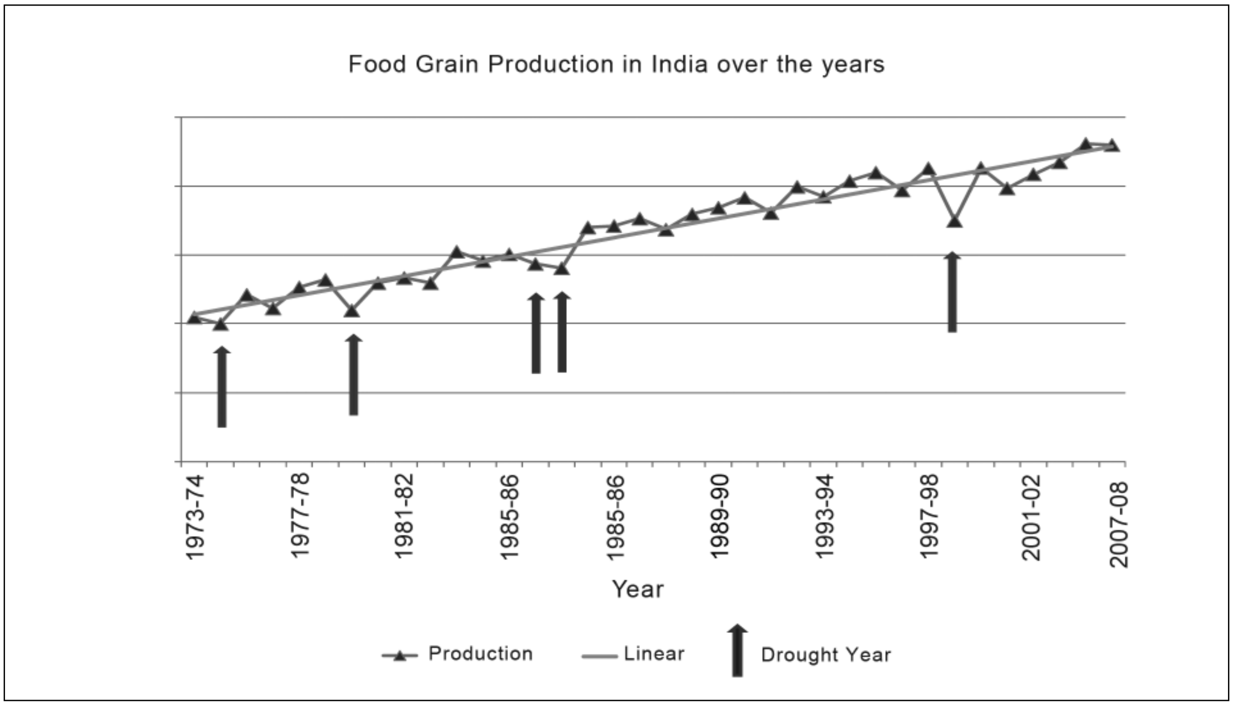

Figure 1. Yearly actual food grain production (million tons) and linear production trend from 1973-1974 to 2007-2008. Note the dip in production in drought years.

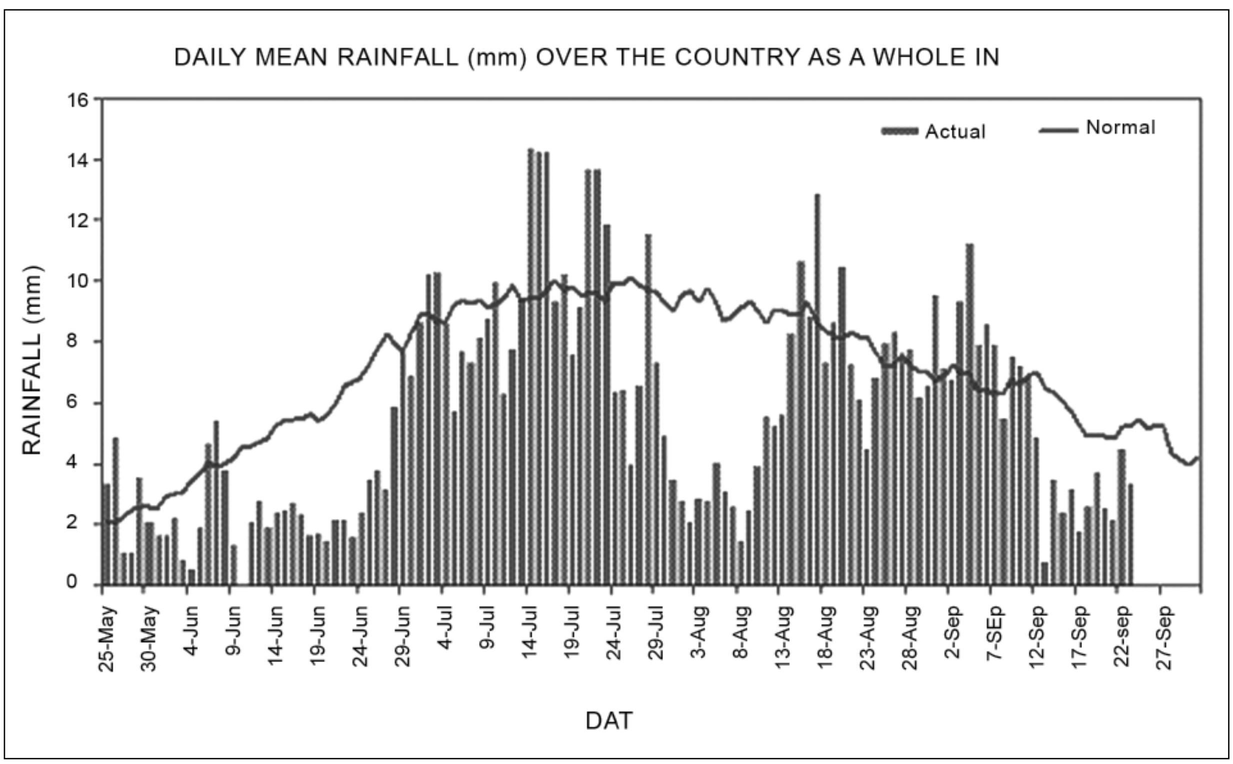

Figure 2. Daily mean rainfall (mm) in India as a whole in the rainy season of 2009.

various time scales. In a few States, daily weather events are recorded in the villages, and transferred through mobile phones to a central hub, which generates updated maps for various kinds of advisory services instantly. Agro-met services of IMD, ICAR, and universities issue weather forecasts and knowledge management advisories, bulletins, and upload information on websites.

3. Drought/calamities declaration processes

Unlike floods, droughts develop gradually, affect larger populations and geographical areas, and phase out slowly. India has witnessed 24 major droughts during the period 1877 to 2009. Hailstorms, cyclones, super-cyclones and accidental fires in matured crops standing in the fields or harvested produce stacked in the field are also common in India. Recently, cold or heat waves in localized pockets also brought down productivity and reduced profits of the farmers. Disease/pest epidemics in crops, poultry, small ruminants and livestock related with climatic changes are also becoming important. The Ministry of Agriculture maintains a comprehensive Weather Watch Group consisting of representatives of Indian Meteorology Department, Ministry of Food and Consumer Affairs (responsible for monitoring prices), Central Water Commission (responsible for monitoring major water supply in reservoirs), ICAR (responsible for R&D), National Rainfed Area Authority (NRAA) (responsible for policy formulation and advice) and others. The Group meets once a week or more frequently whenever required especially during crisis. Inputs received about anomalies in onset of rains, rainfall shortfall, water flow into large reservoirs, loss in cropped area, crop growth conditions, market prices, and the reports of press and media are factored into in arriving at a decision by a State to declare drought for any of its administrative units, from the village level to any higher unit of blocks, *tehsil* (sub-county), district (county) or whole state of any size. The Prime Minister constitutes a 'Group of Ministers' to take immediate policy and executive decisions. A 'Crisis Group' under the Chairmanship of Cabinet Secretary gets activated automatically. Ministry of Agriculture appoints a 'Relief Commissioner' who sets up an IT-enabled dedicated control room at the center (New Delhi) which remains open 24 hours to exchange all kind of information in the country in real time. Similar arrangements are also activated in the states and afflicted districts (626 in all). National Rainfed Area Authority (NRAA) provides technical backstopping for contingency planning and monitoring to alleviate public distress. Recovery of loans from the farmers is deferred or even waived off partially or fully if necessary. In 2007-08, loans amounting to about US $ 14 billion were waived off to ease the burden on farmers. Assistance in the form of food, fodder, feed, seed, other production inputs, and temporary employment was provided.

4. Unique features of the latest drought in 2009

i. One week early arrival of summer rains in South India (Kerala Coast) on 23rd May, 2009, its spread up to 15°N latitude and normal forecast by Indian Meteorological Department (IMD) was a welcome beginning. In anticipation of good rains, sowing of crop was initiated in the Southern region. However, cyclone Aila devastated ecologically important Sunderban wetlands on the East Coast (West Bengal), damaged infrastructure, properties, and land (with saline sea water) and the advance of monsoon to North was stalled. There was stagnation (around 15°N latitude) in the progress of rains northward from 8 to 20 June, 2009 due to cold circulation anomalies in the middle of upper troposphere. This led to a long dry spell from June 9 to 29 (Fig. 2), all India cumulative average rainfall deficiency increased progressively to -54% (Fig. 3) that was comparable to 1926 June deficit. If we consider individual weeks, the deficiency could be as high as -68% (Fig. 4). During this first dry spell, rainfall deficiency was highest in Central India (-73%) followed by North East (-55%), North West India (-49%) and Southern Peninsula (-38%). The crops that germinated early in Southern India withered.

ii. Rainfall became normal for the month of July (as compared to -49% in 2002 and -8% in 1918 droughts) and all India average deficiency fell to -23%. Most of the area under un-irrigated conditions is generally sown during the month of July. A second long dry spell again appeared from July 24 to August 12 and was a major setback to the germinated crops and farmers investments. All India main

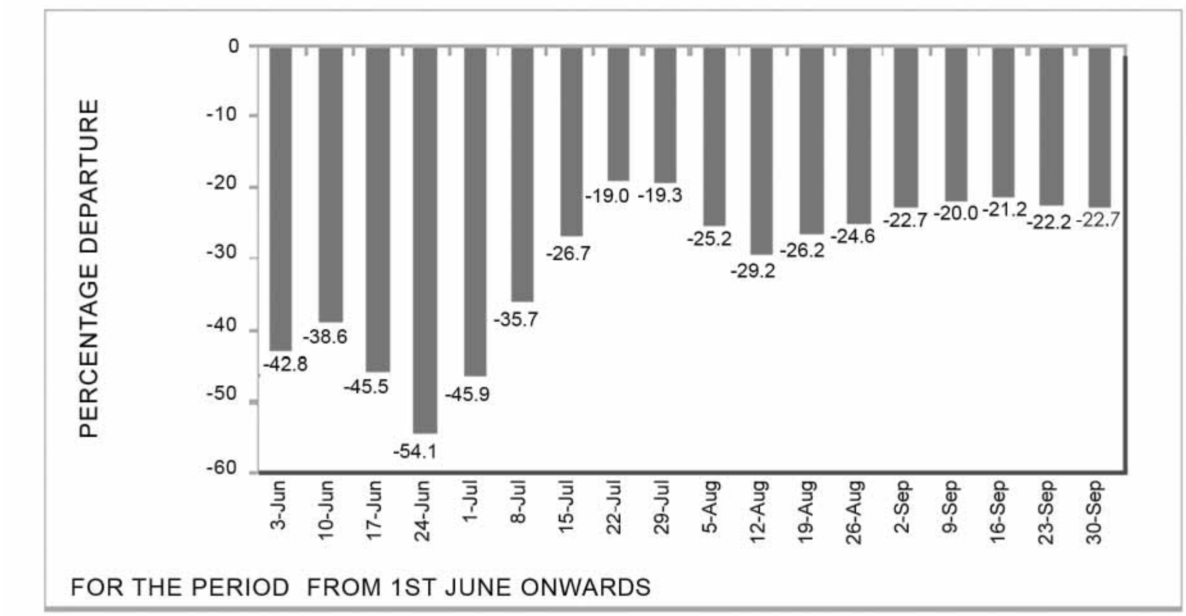

Figure 3. Week-by-week cumulative deviation of the main season rainfall – 2009 (India).

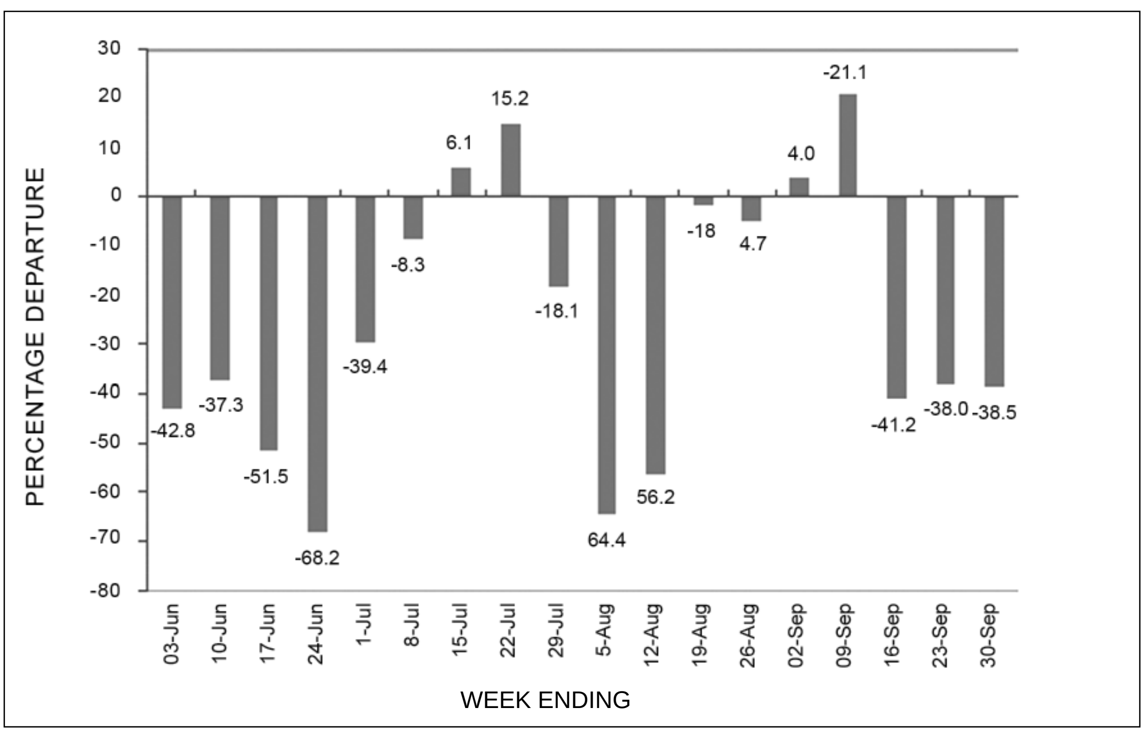

Figure 4. Week-by week deviation of the main season rainfall – 2009 (India).

summer season rainfall of 689.9 mm was deficient by -23% with highest deficiency in North West (-36%), followed by North East (-27%), Central India (-20%) and Southern Peninsula (-4%) and caused concerns about survival and growth of summer crop especially the staple food crop rice being most sensitive to drought. Fortunately the rainfall with 'resumed' on August 13, revived the crops growth and permitted seeding in areas that had remained unsown in a few places. Rainfall of 400 mm (being 600% of the normal and unprecedented in 103 years of history) in three days in the first week of October 2009 caused widespread floods in Krishna basin (South India) damaging crops and property. The withdrawal of rains from north-west was delayed by 15 days from normal.

iii. Unlike 2002, the drought appeared in the flood-prone states of Assam, Bihar and high rainfall regions of Jharkhand and Himachal Pradesh and intensively ground-water irrigated region of North West. Central India, which witnessed highest rainfall deficiency of -73% in June but on 10th September, had floods in seven districts. In the Saurashtra region of Gujarat State in Western India, which is traditionally drought prone, eight districts were flooded in September, and rainfall was above normal. These abnormalities are indicative of changes in the extreme weather events. Floods also revisited the traditional flood prone states of Bihar, West Bengal, Assam and a few pockets in other states of North India. Overall it was a very chaotic rainfall distribution pattern due to global warming.

iv. Water flow into 81 large reservoirs was less than normal except in Krishna basin (Andhra Pradesh, Karnataka and part of Maharashtra).

v. Unlike previous droughts, there was exceptionally high energy demand from farmers to extract ground water. This was a redeeming feature since farmers shifted from demanding empirical relief to seek remediation of situation by trying to maintain productivity and production, of course, at the cost of depleted ground water and high financial input.

vi. During the main summer season, out of 526 meteorological districts, 311 (59%) received deficient or scanty rainfall and the affected states claimed additional central financial assistance of more than US$ 16 billion, which are being scrutinized. Food grain production is likely to go down by about 15 million tonnes. During the 2002 drought, 300 million people in an 180 million ha area were affected and agriculture production was reduced by 29 million tonnes as compared to previous normal years.

vii. In terms of mean, maximum and minimum temperature, 2009 was the warmest year since 1901, especially the Himalayan region, and it caused damage to vegetable production and resulted in the inflation of their prices.

5. A complex basket of economic losses

i. A limited area of crops sown in South India during early rains and maize generally sown during pre summer rains in North India had to be re-sown due to 20 days dry spells in June forcing farmers to incur additional costs of tilling, seeds, fertilizers, labour etc.

ii. Sowing in South India (Rayalseema, Telengana, Marathwada), Eastern India (Assam, Bihar, Jharkhand and UP) was delayed and reduced. Excessive amount of electricity and diesel was consumed in North West (Punjab, Haryana, UP, Bihar) for lifting ground water for transplanting paddy.

iii. Maximum temperature also rose exceptionally high during first dry spell of June which damaged vegetables and their market prices went up. Incidence of animal diseases like Hyperthermia, Ephemeral Fever, reproductive infertility and loss in milk production (especially in cross-bred cattle) increased. High levels of toxic hydrocyanic acid and nitrates and low concentration of phosphorus (poor quality) in fodder were reported in a few cases causing loss of animal productivity. It takes about 3 years to restore loss in animal fertility/reproductivity due to malnutrition.

iv. Reduced production and quality of apples, cherries and tomatoes was reported in Himalayan region.

v. Stagnation in the crop growth of sorghum, castor, and pulses, and stoppage of paddy transplanting and maize sowing was observed during the second dry spell in first half of August. A shortfall of 6.5 million ha (7%) sown area of summer season (consisting of 6.2 million ha under the staple crop of rice alone) as compared to previous year was reported. However, there was an increase of 1.1 million ha area under cotton, which being deep rooted can tolerate drought to some extent. There was however reduction of 1.2 million ha under oil seed crops, which are generally also drought tolerant.

vi. Due to dry conditions and high temperature superfine rice cultivar 'Pusa Basmati 1121' was afflicted by bacterial leaf blight (*Jhulsa Rog*) in North West India.

vii. More than 10% loss in hydro-electric power generation occurred in 2009.

viii. The actual losses due to floods in the Krishna river basin in October will be quantified when major crops are harvested.

ix. Late revival of rains at the time of writing this paper, filling up of some large dams and thousands of small water reservoirs will certainly stop further damages and revive most of the crops. Short-duration pre-winter crops like Toria (*Brassica compestris* var. *toria*.) and pulse crops can be seeded on unsown area and may compensate to some extent the production losses in the pre-winter season.

x. Northwest states of Punjab and Haryana and many others purchased additional electricity in the spot market at double the normal rates to enable their farmers to save standing crop by extracting ground water. Sale of diesel in Punjab State in June was 40% more as compared to the previous normal years. Bihar and UP, having more than 70% bore wells energized with diesel, demanded subsidy on diesel consumed by the farmers. Irrigation by diesel pumps is four times more expensive than electric pumps.

xi. In the earlier recent drought of the year 2002, nearly 22 million ha area was not sown, 47 million ha of sown area was damaged and food production reduced by 29 million tonnes. Losses in food grain production in 2009 are likely to be less due to relatively more favorable distribution pattern as compared to 2002.

6. Immediate relief

To quickly alleviate distress of the affected people provision of an immediate relief is essential in the form of drinking water, food, feed, and medical care. A Calamity Relief Fund (CRF) is provided by the Finance Commission every five years and is left at the disposal of the administration (districts) of the states so that the officials there could provide relief to the affected population immediately after their area is declared as drought or calamity affected. There is also a Calamity Contingency Fund (CCF), which can be used if there are serious economic losses and CRF is inadequate. The states have to put another demand to the federal government for this and release of additional assistance would occur after there is verification of losses.

7. Contingency plans

Based on the forecast of rainfall and consultation with farmers, agricultural scientists and officials of the states, a "Drought Management Strategy - 2009" was prepared by the National Rainfed Area Authority (NRAA). It was uploaded on the internet (www.nraa.gov.in) and widely circulated through print media, radio, television and other sources. Contingency measures for early, mid and late rainfall scenarios for districts within states, agro-ecological regions, and Indian Meteorology sub-divisions were elaborated. The Contingency plan was updated periodically taking in consideration the development of drought scenario. The strategy consisted of immediate-, short-, medium- and long- term measures and only main features of the strategy are summarized here:

i. Alternative crops, fodders, vegetables and their cultivars for early, mid and late sowing for various meteorological sub-divisions, agro-ecological regions and districts of the states were recommended and put on the website. State governments were sensitized by organizing meetings, workshops and discussions with the farmers.

ii. Availability of alternative seeds and other inputs and their sources for various contingencies was publicized.

iii. Various measures for in-situ conservation of rain water, run-off harvesting, its recycling with most efficient micro irrigation systems and recharging of dried up dug wells were elaborated.

iv. Application of fertilizers, soil amendments and inter-cultural operations were suggested.

v. Revising canal irrigation rosters to reschedule equitable distribution of limited water resources for optimizing production was suggested to the irrigation engineers and farmers.

vi. Uninterrupted supply of electricity to run tube wells to improve efficient use of ground water was solicited from the Power Ministry.

8. Offsetting production losses

Food security is the top most priority for the rural people affected by the extreme events, particularly those who are poor. Following compensatory measures were advocated to offset production losses due to drought:

i. Achieving higher productivity elsewhere in the states, regions and districts having normal or above normal rainfall was emphasized so that the overall decrease in food production was minimum. Seed replacement with latest cultivars, extra dose of fertilizers, weeding, diseases and pest control provided many opportunities for increasing production in the areas that were spared from the extreme events of drought and flood.
ii. Inter-cropping with black gram and beans in the maize crop where there was crop mortality and sub-normal plant population was emphasized.
iii. Revival of late rains during second half of August 2009 saved standing crops and a pre-winter extra crop of *Toria* (*Brassica compestris* var. *toria*), horse-gram, niger and fodder on the area where main summer crop could not be sown was targeted to compensate the production losses.
iv. Early sowing of wheat, mustard, chickpea etc. with minimum tillage was advocated to skip losses due to the likely terminal heat in February-March 2010 and to reduce cost of cultivation.
v. There is about 12 million ha of rice-fallow area especially in the high rainfall regions of eastern India. A second crop of pulses, oilseed, vegetables and fodder in winter season by using rainwater harvesting, digging open wells and installing shallow tube-wells was emphasized.
vi. Boro season rice cultivation is a traditional risk-avoiding practice of growing rice during post-rainy and flood free period. This consists of growing relatively long duration (170-180 days) cultivars than the ones (130 days) used in the main summer crop. The productivity of Boro rice is about 2-3 times higher than summer rice but it requires assured irrigation. The Boro rice was promoted in summer flood-prone areas like West Bengal, Assam, Orissa, and Eastern UP, having sufficient good quality ground water resources. Installation and intensification of shallow tube wells or lift irrigation from perennial water streams was recommended to offset drought losses.
vii. Like Boro rice, late-winter or spring season maize during flood or drought risk free period is also of long duration than summer crop with almost double the productivity (6 tonnes /ha). It can be cultivated with assured irrigation in about 100 districts, which were listed in the strategy document.
viii. Groundnut is an important oilseed, feed and fodder crop and it was damaged by the drought of 2009 on about one million ha in Andhra Pradesh. Offsetting losses of its production by growing in the non-traditional late winter/spring season in coastal States of West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Goa, Karnataka, Rajasthan etc. on residual moisture and preferably irrigated conditions was advocated.

9. Traditional and modern safety nets

Traditionally, farmers of arid and desert regions generally stored food, dried fodder and animal feed for two to three years during favorable rainfall seasons/years. Other practices of growing deep- and extensively-rooted drought tolerant multi-purpose trees and rearing of animals, which can migrate during fodder and water scarcity and calamities or even be liquidated are other promising traditions. But these are not enough in the present context. Seasonal migration of persons to earn income from elsewhere creates social disturbances and is also inadequate. Some of the following modern or add-on safety nets take into account the traditional mechanisms, emerging demands and supplies, new technologies, alternative governance, innovative policies and programs.

9.1 Employment guarantee in rural areas

It was necessary to prevent seasonal outmigration that results in several socio-economic disturbances. Assurance of employment of 100 days per annum per family to the unskilled worker in the rural areas within 15 days of filing application to the elected village representative has been provided by an Act of 2005. Alternatively compensatory payment is legally provided. The rules ensure equity, inclusiveness, transparency, prompt weekly payments and social audit, and eliminate all chances of pilferage and corruption. The works create durable and productive assets by conserving and managing land, water, forests and other natural resources in an integrated manner to generate self-employment. A 40% of budgetary provision ensures creation of assets by 60% of wage component. It also enhances access to food and improves livelihoods.

9.2 Public distribution system and food grain buffer stocks

Department of Food ensures prescribed minimum quantities of wheat in April and rice in November in government stocks and the present (October 2009) stock of food grains of 50 million tonnes was in excess of the minimum stipulation. This stock can feed the country for 13 months. Farmers are encouraged to grow food grains by declaring an attractive 'Minimum Support Price' at the sowing time and by assuring procurement in the grain market by the Central and State procurement agencies. Prompt payment to farmers of purchased grains, preferably through the bank accounts, scientific storage, and movement of stocks to the scarcity regions through railway network are well planned. In case of shortage in the procurement of food grains to meet the minimum level of the stocks, duty free imports are made to regulate the market prices and public sentiments.

9.3 Managing consumer prices

In 2009, there was negative inflation in the Weighted Price Index of commodities of India due to economic recession but prices of food articles including fruits and vegetable inflated due to drought. The price rise of grain was not due to imbalanced demand-supply as there was sufficient reserved stock but due to speculations and other market sentiments. Enforcement of Essential Commodities Act and other laws against hoarding and forward trading was enforced to check price inflation. Release of stocks into the market from the buffer pool, public display of stocks by traders, and surprise raids on the stores of unscrupulous hoarders frequently occurred to prevent artificial inflation.

9.4 Innovative insurance derivatives

All farmers taking loans are provided with an insurance cover subsidized by the Government of India and claims are settled by the banks if there is damage to the crops after assessing losses. Farmers, especially those cultivating cash crops, ask for more pragmatic weather- based insurance derivatives where claims can be settled within 2-3 weeks as compared to 4-6 months required in the conventional insurance schemes. Similarly there are schemes available for the insurance of livestock, other products, and entire farming system. The insurance systems are being continuously improved depending upon the feed-back on the valuation system and promptness in the delivery of the claims.

9.5 Credit services

With the declaration of drought and other natural calamities, credit and interest repayments are normally deferred and in a few cases of distress they were even waived off partially or wholly and the costs borne by the government of India. Under highly risky or uncertain rainfed situation different products of credit with longer duration of re-payment, rolling system of the service, and loan for domestic consumption are also being devised to prevent diversion of the crop loans for non-productive or consumptive purposes. Institutionalized credit is much cheaper than that provided by private money lenders, local traders, and marketing commission agents. Micro-financing especially by women self-help groups is quite prompt with minimum transaction cost and is quite popular mechanism of getting short-term loans. Some corporate agencies, especially in dairy sector, also advance loans to the farmers, provide animal health services, and enable insurance with buy back system. Marketing commission agents, local traders and intermediaries meet out major credit requirements of rural sector but it is difficult to cover them under loan waiver scheme. The recent loan waiver of US$ 14 billion to alleviate impact of drought disaster on Indian farmers has thrown up new issues. Those farmers who paid back their loans could not benefit and waiver to others amounted to rewarding defaulters. Banks became cautious of fresh loaning since farmers may not repay presuming subsequent waivers.

9.6 Fodder and feed banks

In India about 67% of the fodder requirement is met by the crop residues, which become a scarce commodity during drought. The traditional drought affected farmers have devised ways and means to store dried stalks of sorghum, pearl millet, grasses, etc. for a period up to 3 years. Fodders and water are also moved through railway network free of cost from non drought affected areas to the drought afflicted regions. Fortification of the dried fodder with various minerals and sugarcane molasses, making feed blocks, and baling bulky fodder material for easy handling, transportation and reducing storage space are the other activities of the safety net.

9.7 Shelter belts

Micro and major shelter belts especially under arid and desert conditions were very effective in preventing loss of soil moisture and adverse effects on crop of cold and heat waves.

9.8 Rainwater harvesting and groundwater re-charging

Water management from ridge to valley of a watershed is the most important input for moderating adverse effect of cold/heat wave, drought and other stresses to maintain productivity and alleviate vulnerability. There are many preventive and proactive interventions to mitigate or reduce severity of the drought. These measures are specifically designed to harvest rainwater during the normal rainfall periods both for limited irrigation and ground water re-charging. Long dry spells during the rainy season are also very common and the rainwater harvested into ponds, check dams, tanks, re-charged profile and ground water aquifers are very handy to save the crops in such seasons. Adequate budget is provided to take up watershed management program with participation of local communities in the country. Convergence with employment guarantee and other funds to create watershed assets is also being promoted. Capacity building of technical manpower and community mobilization for participatory processes is given very high priority.

9.9 Non-conventional renewable energy

Energy is important for extension and market related IT based real time information exchanged through VSATs in the remote rural areas. Decentralized production and consumption of electricity by wind and solar farming in the arid and desert region has tremendous opportunities. Desalinization of poor quality water for drinking and protected cultivation in green houses is possible by harnessing solar, wind and tidal potentials. New technologies are in the pipeline for green power generation for combating climatic changes.

9.10 Harnessing genetic potential

This approach of safety nets is designed as a medium- and long-term measure of reducing vulnerability. Depending upon the rainfall, topography, soil profile characteristic etc., lengths of the crop growing periods are modeled for various agro-ecologies. The length of growing period is primarily derived from the moisture holding and releasing capacity of the soil, topography and rainfall pattern. Length of growing period under rainfed conditions varies from less than 60 to more than 270 days in different parts of India. There are crop cultivars of moth bean (pulse crop) with very deep root system, which can mature in 65 days and the crop is ideally suited for semi-arid and arid region. Cultivars of soybean been of 85 days and of pearl millet of 70 days duration are now available as against 120 to 130 days of traditional cultivars. The whole idea in genetic manipulation is to evolve a large range of crops and varieties to match the spectrum of length of growing period of various micro-ecologies and rainfall deficiencies. Similarly the ‘Tharparkar’ breed of cow in the Rajasthan desert produces a higher yield when the temperature is very high as compared to the cross-bred cattle that lose their appetite and milk production during droughts. Some of the indigenous breeds of sheep can withstand highly saline drinking water normally prevalent in arid regions. There is a multipurpose tree *Khejri* (*Prosopis cinerarea*) with very extensive lateral and deep taproot system, which can tap large volume of soil for moisture and can survive 7-8 years of scanty rainfall. There are immense genetic possibilities in various crops, trees, animal breeds, grasses, which are quite tolerant to drought and are being genetically improved upon.

9.11 Out-of-the-box solutions

Economic resilience and robustness of rural communities is the best way of shielding them from extreme weather events. Companies Act 1956 has been amended in 2002 to set up Primary Producers’ Companies for incorporating non-performing cooperative societies. Amended provisions ensure that Primary Producers’ Companies will remain with the farmers, herders, and art and craft persons. They can further have forward linkages with Corporate Social Responsibility (CSR) to benefit from aggregation, processing, value addition and marketing of small holders, herders and producers. The primary producers should be able to share 20-40% of the added value by the corporate sector.

10. Adaptation and mitigation

Short- and long-term adjustments in terms of evolving new crops and cultivars, improved land use system, reducing production of green house gases (GHG) and improving infra-structure are needed to reduce vulnerability. India is spending more than 2% of its GDP as adaptation cost and 8 missions have been launched for mitigation. Substantial progress has been made in cutting down GHG emissions from the energy sector through carbon trading. C-trading is evolving in the forestry, horticulture and agro-forestry sector. There is unprecedented interest in nuclear energy trading being carbon neutral. Thorium based technologies are being evolved in addition to the uranium fuel.

Energy efficiency for urea production has improved four times. By law, paddy rice cannot be transplanted before 10th June in Punjab and 15th June in Haryana and this is saving 20% ground water depletion a year since 2007. Anaerobic cultivation of rice to cut down GHG production and save water is being perfected. 'Basmati -1121' and 'C-252' rice cultivars need less water and are being promoted. Small efforts as they may look, they can surely contribute to mitigation of climate change in the long run.

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Impacts of climate change on food security and livelihoods

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Abstract

Developing countries are projected to be hard hit by climate change, particularly South Asia and Sub-Saharan Africa. Many developing countries are highly dependent on agriculture for food security, and as source of livelihood in rural areas and economic growth. To estimate the impacts of climate change on agriculture, the International Food Policy Research Institute has assessed the impacts on production of major cereal commodities under a number of climate change scenarios and General Circulation Models (GCM). Using the National Center for Agricultural Research GCM, and A2 climate change scenario from the Intergovernmental Panel on Climate Change, it is projected that global wheat production would be reduced by 47 percent, rice by 27 percent and maize by 13 percent in 2050 under irrigated conditions compared to a no-climate change scenario in 2050. Rainfed production is estimated to drop by 28 percent for wheat, 16 percent for maize, and 13 percent for rice in 2050 compared to a no-climate change scenario in 2050. Lower production boosts food prices compared to the no-climate change scenario, reducing projected calorie consumption by 22 percent in developing countries in 2050 compared to the no-climate change scenario and causing projected child malnutrition to rise by 21 percent. These impacts would significantly worsen food security, especially for the poor and vulnerable groups in rural communities. Critical policy reforms and agricultural adaptation funding are required for all countries in the developing world. Investments in agricultural research, irrigation and water use efficiency, and rural roads need to be increased substantially to counteract the effects of climate change.

Keywords: cereal production under changing climate, General Circulation Model, food security, investment in research and infrastructure.

Executive Summary*

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The Challenge

The unimpeded growth of greenhouse gas emissions is raising the earth's temperature. The consequences include melting glaciers, more precipitation, more and more extreme weather events, and shifting seasons. The accelerating pace of climate change, combined with global population and income growth, threatens food security everywhere.

Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation. Changes in precipitation patterns increase the likelihood of short-run crop failures and long-run production declines. Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security.

Populations in the developing world, which are already vulnerable and food insecure, are likely to be the most seriously affected. In 2005, nearly half of the economically active population in developing countries—2.5 billion people—relied on agriculture for its livelihood. Today, 75 percent of the world's poor live in rural areas.

This Food Policy Report presents research results that quantify the climate-change impacts mentioned above, assesses the consequences for food security, and estimates the investments that would offset the negative consequences for human well-being.

This analysis brings together, for the first time, detailed modeling of crop growth under climate change with insights from an extremely detailed global agriculture model, using two climate scenarios to simulate future climate. The results of the analysis suggest that agriculture and human well-being will be negatively affected by climate change:

- In developing countries, climate change will cause yield declines for the most important crops. South Asia will be particularly hard hit.
- Climate change will have varying effects on irrigated yields across regions, but irrigated yields for all crops in South Asia will experience large declines.
- Climate change will result in additional price increases for the most important agricultural crops–rice, wheat, maize, and soybeans. Higher feed prices will result in higher meat prices. As a result, climate change will reduce the growth in meat consumption slightly and cause a more substantial fall in cereals consumption.
- Calorie availability in 2050 will not only be lower than in the no–climate-change scenario—it will actually decline relative to 2000 levels throughout the developing world.
- By 2050, the decline in calorie availability will increase child malnutrition by 20 percent relative to a world with no climate change. Climate change will eliminate much of the improvement in child malnourishment levels that would occur with no climate change.
- Thus, aggressive agricultural productivity investments of US$7.1–7.3 billion are needed to raise calorie consumption enough to offset the negative impacts of climate change on the health and well-being of children.

Recommendations

The results of this analysis suggest the following policy and program recommendations.

1. Design and implement good overall development policies and programs.

Given the current uncertainty about location-specific effects of climate change, good development policies and programs are also the best climate-change adaptation investments. A pro-growth, pro-poor development agenda that supports agricultural sustainability also contributes to food security and climate-change adaptation in the developing world. Adaptation to climate change is easier when individuals have more resources and operate in an economic environment that is flexible and responsive.

2. Increase investments in agricultural productivity.

Even without climate change, greater investments in agricultural science and technology are needed to meet the demands of a world population expected to reach 9 billion by 2050. Many of these people will live in the developing world, have higher incomes, and desire a more diverse diet. Agricultural science- and technology-based solutions are essential to meet those demands. Climate change places new and more challenging demands on agricultural productivity. Crop and livestock productivity-enhancing research, including biotechnology, will be essential to help overcome stresses due to climate change. Crops and livestock are needed that are doing reasonably well in a range of production environments rather than extremely well in a narrow set of climate conditions. Research on dietary changes in food animals and changes in irrigation-management practices is needed to reduce methane emissions. One of the key lessons of the Green Revolution is that improved agricultural productivity, even if not targeted to the poorest of the poor, can be a powerful mechanism for alleviating poverty indirectly by creating jobs and lowering food prices. Productivity enhancements that increase farmers' resilience in the face of climate-change pressures will likely have similar poverty-reducing effects. Rural infrastructure is essential if farmers are to take advantage of improved crop varieties and management techniques. Higher yields and more cropped area require maintaining and increasing the density of rural road networks to increase access to markets and reduce transaction costs. Investments in irrigation infrastructure are also needed, especially to improve the efficiency of water use, but care must be taken to avoid investments in places where water availability is likely to decline.

3. Reinvigorate national research and extension programs.

Investment in laboratory scientists and the infrastructure they require is needed. Partnerships with other national systems and international centers are part of the solution. Collaboration with local farmers, input suppliers, traders, and consumer groups is also essential for effective development and dissemination of locally appropriate, cost-effective techniques and cultivars to help revitalize communications among farmers, scientists, and other stakeholders to meet the challenges of climate change. Within countries, extension programs can play a key role in information sharing by transferring technology, facilitating interaction, building capacity among farmers, and encouraging farmers to form their own networks. Extension services that specifically address climate-change adaptation include disseminating local cultivars of drought-resistant crop varieties, teaching improved management systems, and gathering information to facilitate national research work. Farmer organizations can be an effective information-sharing mechanism and have the potential to provide cost-effective links between government efforts and farmer activities.

4. Improve global data collection, dissemination, and analysis.

Climate change will have dramatic consequences for agriculture. However, substantial uncertainty remains about where the effects will be greatest. These uncertainties make it challenging to move forward on policies to combat the effects of climate change. Global efforts to collect and disseminate data on the spatial nature of agriculture need to be strengthened. Regular, repeated observations of the surface of the earth via remote sensing are critical. Funding for national statistical programs should be increased so that they can fulfill the task of monitoring global change. Understanding agriculture–climate interactions well enough to support adaptation and mitigation activities based on land use requires major improvements in data collection, dissemination, and analysis.

5. Make agricultural adaptation a key agenda point within the international climate negotiation process.

International climate negotiations provide a window of opportunity for governments and civil-society organizations to advance proposals for practical actions on adaptation in agriculture.

6. Recognize that enhanced food security and climate-change adaptation go hand in hand.

Climate change will pose huge challenges to food-security efforts. Hence, any activity that supports agricultural adaptation also enhances food security. Conversely, anything that results in increased food security will provide the poor, especially the rural poor, with the resources that will help them adapt to climate change.

7. Support community-based adaptation strategies.

Crop and livestock productivity, market access, and the effects of climate all are extremely location specific. International development agencies and national governments should work to ensure that technical, financial, and capacity-building support reaches local communities. They should also encourage community participation in national adaptation planning processes. Community-based adaptation strategies can help rural communities strengthen their capacity to cope with disasters, improve their land-management skills, and diversify their livelihoods. While national adaptation policies and strategies are important, the implementation of these strategies at the local level will be the ultimate test of the effectiveness of adaptation.

8. Increase funding for adaptation programs by at least an additional $7 billion per year.

At least $7 billion per year in additional funding is required to finance the research, rural infrastructure, and irrigation investments needed to offset the negative effects of climate change on human well-being. The mix of investments differs by region: Sub-Saharan Africa requires the greatest overall investment and a greater share of investments in roads, Latin America in agricultural research, and Asia in irrigation efficiency.

Adapting to climate change: the importance of *ex situ* conservation of crop genetic diversity

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Abstract

Climate change is impacting agriculture in a plethora of ways, some of which are less immediately visible than others. The diversity contained within plant genetic resources provides the variability needed for adaptation, and therefore will serve as a key element in maintaining food production under novel temperature, precipitation, and pest and disease conditions. This diversity is increasingly threatened, and there is an urgent need to collect and secure plant genetic resources for the global community. Likewise, the use of these resources to mitigate and adapt to climate change must be increased in order to proactively address the needs of agriculture, and this requires a coordinated effort from international, regional, national and local stakeholders. Countries are interdependent regarding genetic resources for food production, and the political framework exists to share and use these resources to adapt to climate change. The Global Crop Diversity Trust and its partners worldwide are working to prepare for climate change through collecting, securing, improving the management of, researching, and using plant genetic resources.

Keywords: adaptation, climate change, crop diversity, *ex situ* conservation, plant genetic resources.

Introduction

Agriculture is facing an increasing number of challenges that limit the prospects for maintaining, much less increasing, food production. Energy shortages and unreliability, scarcity of water, arable land and other natural resource limitations, population growth, development pressures, soil erosion and degradation, low stockpiles and high food prices constrain the potential for achieving food security and freedom from hunger called for by the Millennium Development Goals (2000) and various food summits (e.g. World Summit on Food Security 2009). Decades of underinvestment in agricultural research have limited the production gains possible through genetic and agronomic improvements. Adding climate change to this list of challenges has fomented what can be called a 'perfect storm' (Godfray et al. 2010).

Climate change is affecting food production and the management of plant genetic resources (PGR) in farmer's fields and in the wild (Bryan et al. 2009; Gbetibouo 2009; Maddison 2007; Mortimore and Adams 2001; Nhemachena and Hassan 2007; Robinson 2005; Thomas et al. 2007; Torre 2009; Unganai 1996), and impacts in numerous regions are projected to increase in severity (Battisti and Naylor 2009; Burke et al. 2009; Hulme et al. 2001; Kurukulasuriya et al. 2006; Lobell et al. 2008; Williams et al. 2007).

Average temperature during the crop growing season in many developing countries in a half century from now will fall outside the range experienced in the past 100 years. In other words, in many countries that already have problems of food insecurity, the coolest growing seasons of the future will be hotter than the warmest seasons of the past (Battisti and Naylor 2009). Many crops are sensitive to small changes in temperature, affecting development, fertilization, and fruit and grain set. Peng et al. (2004) found a 10% decline in rice grain yield associated with each 1° C increase in growing season minimum temperature. Farming systems will not only have to cope with the new 'average' temperatures, they will have to deal with more fluctuations, greater extremes, and seasonality changes, not only of temperature, but also humidity, precipitation, pest, disease and weed pressures, and more.

Climate change and need for crop adaptation

The extent of climate change that now seems inevitable casts doubt on projections of food production increases for 2020 and beyond. For example, the business-as-usual projected annual crop production growth rates of the International Food Policy Research Institute (IFPRI) for maize for southern sub-Saharan Africa is 2.4% up to the year 2025 (Rosegrant et al. 2005), whereas climate change impact studies for maize in that region project a decrease in production of more than 25% by 2030 (Lobell et al. 2008). As impacts increase in severity, they will test the ability of breeders to produce new adapted cultivars in order to address the needs of farmers whose crops no longer grow as before (Koski 1997).

Remarkably, we have a living historical record of crop adaptation, a record of the successes of countless experiments in adaptation. This is held in the crop diversity that has been collected, typically in the form of seeds, and stored in a frozen state in genebanks around the world. Today these genebanks contain approximately 1.5 million distinct samples (Fowler and Hodgkin 2004), including over 100 000 different types of rice and wheat. This diversity is what is left of a 13 000 year experiment, a living legacy of the interaction of crops with people and their environment, including climate. This diversity also constitutes the future, providing the genetic base for crop improvement and the genetic variability for adaptation to new climates. As the world reaches its limits in arable land and other resources, crop improvement is projected to be the source of an increasingly dominant percentage in future production gains (Godfray et al. 2010; Hubert et al. 2010). Crop diversity is a resource that stands, as agricultural historian and geneticist Jack Harlan once put it, "between us and catastrophic starvation on a scale we cannot imagine" (Harlan 1972).

Urgency to fill gaps in collections of genetic diversity

Despite the vast crop diversity that has been collected, we cannot assume that genebanks contain all the diversity needed to meet the challenges of the future. Although a general trend of increased temperature is projected across much of the planet, other climate factors vary by region and locality and are difficult to predict with confidence.

What exact traits will be needed in a particular agricultural region in the future is therefore an ongoing, evolving question; adaptation is a moving target. While the diversity of major cereal crops has been fairly well collected, this is not the case for other crops such as legumes, root and tuber crops, vegetables, and fruit and nut trees. In all crop genepools significant taxonomic, geographic, and environmental gaps remain to be filled in *ex situ* collections (CIAT 2009; FAO 1998). A general lack of information regarding the diversity held in genebanks further limits the ability to ascertain whether the crop genetic diversity that is conserved is useful for adaptation.

The loss of biodiversity from land use changes, habitat fragmentation, the modernization of agriculture, urbanization, invasive species, and other factors continues around the world and the increasing severity of climate change is projected to further drive populations toward extinction (Brooks et al. 2006; Thuiller et al. 2005; FAO 2008; Maxted and Kell 2009; Wilkes 1977; Maxted 2003; Meilleur and Hodgkin 2004; Graham 1988; Jarvis et al. 2003; Jarvis et al. 2008).

Ironically, the resources essential to adaptation to climate change are also those threatened by it. It is likely that species will have to migrate in the face of climate change, and this may significantly impact the effectiveness of *in situ* conservation strategies (Graham 1988; Hannah et al. 2002; Malcolm et al. 2002; Loarie et al. 2009; Opdam and Wascher 2004; Pearson 2006; Pearson and Dawson 2005;Williams et al. 2005).

The urgency to fill gaps in plant genetic resource collections and to conserve unique diversity before it is extirpated *in situ* has been recognized for decades (Frankel and Bennett 1970; Harlan 1972; Hawkes 1971; Wilkes 1977; Zedan 1995), and continues to be emphasized (Burke et al. 2009; Damiana 2008; Khoury et al. 2010; Kiambi et al. 2005; Maxted et al. 2008; Wilkes 2007; Veteläinen et al. 2009). Many of the international collections managed by the Consultative Group on International Agricultural Research (CGIAR) for the world community are currently emphasizing the need to collect (Halewood and Sood 2006), and U.S. germplasm experts ranked acquiring additional materials as the number one funding priority for the U.S. germplasm system (Zohrabian et al. 2003). Despite this prioritization, the number of new accessions collected per annum has on average decreased since the mid-1980's (FAO 2009; Fowler et al. 2001).

A major new effort in collecting must be undertaken if genebanks are to have a full and adequate representation of crop genepools, perhaps with a particular focus on finding and conserving genes helpful for climate change adaptation. This may lead in many cases to the need to collect at the geographic, topographic, and environmental extremes of crop distributions, where the crops have historically encountered their most radical climatic and other environmental challenges. Collecting is likely to increasingly focus as well on the wider diversity found within crop genepools, particularly that present in wild relatives.

Crop wild relatives

Crop wild relatives (CWR) have become a well-established source of genes for crop improvement, particularly for pest and disease resistance and tolerance to abiotic stress, for crops such as banana, barley, beans, cassava, chickpea, lettuce, maize, oats, pearl millet, potatoes, rice, sugar cane, sunflower, tomato, and wheat (Damiana 2008; FAO 2009; Gur and Zamir 2004; Hajjar and Hodgkin 2007; Hoisington 1999; McCouch et al. 2006; Maxted and Kell 2009; Phillips and Meilleur 1998; Tanksley and McCouch 1997). The wild portion of a crop genepool generally contains much greater genetic variation than the cultivated taxa (Damiana 2008; Petersen et al. 1994; Vollbrecht and Sigmon 2005), and this variation has contributed significantly to agricultural output (Phillips and Meilleur 1998). In the past 20 years, there has been a steady increase in the rate of release of cultivars containing genes from CWR, and the contributions should increase as the development of molecular technologies makes identification and utilization of diverse germplasm more efficient (Hajjar and Hodgkin 2007; Prescott-Allen and Prescott-Allen 1986; Singh 2001;Tanksley and McCouch 1997).

The conservation of CWR is increasingly widely recognized as a high priority (Damiana 2008; Heywood 2008; Jarvis et al. 2003; Jarvis et al. 2008; Khoury et al. 2010; Maxted 2003; Maxted and Kell 2009; Meilleur and Hodgkin 2004; Maxted et al. 2008;), but this has yet to result in adequate conservation. Estimates of the percent of *ex situ* holdings worldwide comprised of wild or CWR accessions range from 2% to 18% (Astley 1991; FAO 2009; Hammer et al. 2003; Maxted and Kell 2009). Very large gaps in species coverage remain to be filled; Maxted and Kell (2009) estimated that 94% of European crop wild relative species are entirely missing from *ex situ* collections.

Taking care of PGR

We also must be careful not to take for granted that the diversity held in genebanks is cared for properly. The world's genebanks lack an efficient, internationally coordinated system to maintain high standards, and many genebanks face funding insecurity. Vital genebank activities, such as the periodic regeneration of accessions, are constrained by lack of funding, expertise, and research, leading to regeneration backlogs and the subsequent loss of unique genetic diversity (Dulloo et al. 2009; Engels and Rao 1995; FAO 2009; Fowler and Hodgkin 2004; Khoury et al. 2010; Schoen et al. 1998). And genebanks are not exempt from the dangers of natural disasters, as experienced by the Philippines National Gene Bank during cyclone Xangsane in September 2006, nor by war and civil strife, as in recent years in Iraq and Afghanistan.

Global interdependence on PGR

The worldwide interdependence on plant genetic resources for food production is evident at the dietary (Fowler and Hodgkin 2004), the varietal, and at the pedigree (or gene) level (Gollin 1998). No country grows only those crops that originated within its borders, and the interdependence on genetic diversity for adaptation will only increase with climate change (Burke et al. 2009). The resources that became extinct the day cyclone Xangsane flooded the Philippine genebank may have been exactly the resources needed in the future to breed a climate-ready crop in Australia, in Ghana or elsewhere. With less and less climatic overlap between present and future conditions, we are more than ever reliant on genetic resources from elsewhere.

The conservation of crop diversity in any given country or region is relevant to all of us.

Food and agriculture-related international accords, particularly the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO 2002) and the Global Plan of Action for the Conservation and Sustainable Use of PGR for Food and Agriculture (FAO 1996) recognize this global interdependence for food production and for this reason call for the formation of an efficient and effective global system for the conservation and use of crop diversity. The political and legislative framework for facilitated access to plant genetic resources, which will be essential under rapid climate change, has been established by the ITPGRFA.

How do we prepare for the increasing severity of the storm affecting agriculture? Breeding takes time, and there is therefore no time to lose if we are going to be able to adapt to climate change and minimize the damages to crop production, societal stability, and livelihoods. Crop diversity must be collected before it is lost, PGR in genebanks must be properly cared for, genebank collections must be screened for valuable traits, and this diversity must be made easily available for use.

Global Crop Diversity Trust

The Global Crop Diversity Trust (the Trust) was created in large part to address the shortcomings in the custodianship of crop diversity conserved *ex situ*. It seeks to build a non-depleting endowment that will generate sufficient income annually to underpin the conservation of crop diversity, and through this create a rational, efficient, effective, and sustainable global system to ensure both conservation and availability of this diversity. Such a system would ensure that each distinct sample is conserved in a well-managed facility meeting international standards, adequately safety duplicated for security, and made available for research and breeding without undue constraints. As a further safety backup, seed samples should be stored in the Svalbard Global Seed Vault, a facility that provides an ultimate safety net for existing genebank collections.

With support from Grains Research and Development Corporation (GRDC) and others, the Trust has mobilized scientists and specialists worldwide to develop crop and regional strategies that identify the most genetically diverse collections in the world and outline the priority needs for their conservation and use. Starting in 2007, the Trust has begun to make long-term conservation grants that secure the most important collections- 17 collections of 14 globally important crops at the moment. The Trust has supported Geographical Information Systems (GIS) experts at the Centro Internacional de Agricultura Tropical (CIAT) and Bioversity International to identify gaps in major crop genepools worldwide, with a focus on CWR, and to develop a methodology for identifying collecting priorities.

With grants from the United Nations Foundation, funded by the Bill & Melinda Gates Foundation, and from GRDC, the Trust is supporting work to collect, secure, and use genebank collections, including the regeneration of threatened accessions held in national institutes, safety duplication of these accessions, targeted collecting, data generation (characterization and evaluation), data management and sharing, research, and cryopreservation of vegetative crops. Through these projects, almost 100 000 distinct crop accessions will be rescued and secured, and much new information on crop diversity generated and made available.

A state of the art genebank data management software system (GRIN-Global), to be freely available for use in genebanks worldwide, is under development in partnership with the USDA and Bioversity International. Bioversity, the secretariat of the ITPGRFA, and the Trust are also partnering to develop an integrated global information portal linking genebank databases and existing crop and regional databases together in order to create an information source useful for the identification, analysis and requesting of accessions worldwide. The aim is to provide access to passport, characterization, and other data on the entire *ex situ* diversity available for agricultural crops. Further information on the activities of the Trust and its partners can be found at www.croptrust.org.

What would it take to collect, secure forever, and make available for use the crop diversity essential for food production, food security, and climate change adaptation? The Trust estimates that this work can be done for a crop genepool by placing $USD 4 million for lentils, and perhaps $30 million for rice, into an endowment fund. Their continued existence and availability should not be taken for granted. The cost of conserving crop diversity is relatively small and the benefits incredibly large. And the costs added to repairing disasters created by climate change will increase significantly if this crop diversity is not conserved and used. Now more than ever, "the future of the human race rides on these materials" (Harlan 1972).

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Faba bean and its importance for food security in the developing world

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Abstract

Faba bean (*Vicia faba)* has been a well known crop in the Old World, spreading in recent times to other regions such as Canada and Australia. It has been used both for animal and human consumption, as well as for improving soil fertility because of its capacity to fix atmospheric nitrogen as well as possibility to use it as a green manure crop. It is still a basic staple in the diets of people in several countries. A perfect complement to the cereals in diets of people from the ancient times, faba bean has also been an excellent component of the crop rotations. In spite of all of its merits, the world cultivated area of faba bean has decreased in the last 50 years. China is the leading producer followed by Ethiopia, Egypt and France. For green pods and seeds, Bolivia and Algeria were the countries with the largest area, but China and Morocco were the highest producers. Crop improvement efforts in the past have helped solve some of the classical constraints, although the spread of valuable cultivars has not been as successful as required. The genetical aspects of non-nutritional principles are now well understood and useful markers are available. Several sources of resistance to most common diseases are known and have been transferred to commercial cultivars. Resistance/tolerance to virus and bacterial diseases, stem nematode as well as traditional legume pests such as bruchids and sitona weevil still needs to be evaluated. The yield gap in most countries is still very large; but the yield can easily be doubled in most regions. There is a potential to transfer desirable traits from diverse sources through the possibilities opened by transformation and *in vitro* regeneration, although the efficiency of the new techniques still needs to be improved. The use of the model species *Medicago truncatula* is facilitating the comparative mapping of traditional legume crops including faba bean, and this may bring some new perspectives to the faba bean breeding efforts. While waiting for the perfection of new research approaches, using traditional plant breeding protocols and marker assisted selection (MAS) for disease resistance and quality traits can be the best approach for getting the desired materials in the shorter time in most countries.

Keywords: disease and pest resistance, genetic characterization, molecular markers, non-nutritional factors, protein content, role in feed and food, traditional breeding.

Introduction

According to FAO, the world agriculture production should double by 2050 to guarantee food for an expected world population of about 9,000 million inhabitants. An increasing population is the strongest challenge to produce not only more food but also more plant-derived products. To fulfill the needs, we have to increase the production in a sustainable agriculture, maintaining the potential of the environment and even improving it. Among the challenges to increasing the food production are the impact of climatic change, the environmental impacts of agriculture, the rising costs of food production, the concern for food safety and the public resistance to chemical use.

New crops are indeed needed and some efforts are being devoted to domesticate wild plants, as for example, as a source of molecules needed by many industrial processes. Other crops are being used for new uses, such as sugarcane for bioalcohol in Brazil, or even maize and other cereals for the same purpose in other countries. But why not to start with improving and even remodelling traditional crops, especially those that do maintain and improve the soil fertility while providing food and feed? Pulses are a good example of such crops and these are well known to farmers in most countries. Most pulses are among the crops first domesticated along with cereals and used in the diet. In spite of their cultivation since ancient times and excellent characteristics, pulses, however, do not figure among the important crops at present. An exception is soybean, but ranking first not as a pulse but as an oil crop. To a lesser degree, the same can be said of peanuts. The main reason for low area and production of pulses is the little research attention they have received because they were not typical and well appreciated crops in countries leading the agricultural revolution and the application of the scientific method to plant breeding in the late XVIII and the early XIX centuries. Except for some work on common beans and to some extent on peas, most pulses had to wait until the second half of the XX century as an object for plant breeding. The lag in research is still very big.

Yields, in general, do not reach 1t/ha. In fact, most national averages indicate yields in the range of 0.6-0.8 t/ha, i.e., roughly the same yield level that had been attained hundred years ago, a fact pointing to the obvious lack of research. High yield of peas is the result of the research done in some developed countries, and to some extent the same is true for faba bean (yield is also over 1t/ha) although it received research attention later than pea. The yield of common beans is low because it is cultivated in many developing regions, with little crop improvement. The general conclusion from the yield figures of pulses is that when research is done on them, there is a positive result.

A fact that should not be forgotten when comparing cereal and legume yields is that the legumes have a protein content double or triple that of the cereals; and among the basic metabolites produced by plant, proteins are the most energy-expensive. Very likely, a legume will never reach the yield level of a cereal and if by genetic engineering a cereal is transformed in a N-fixing plant as efficient as a legume, its yields would surely reduce. Although the *Rhizobium-legume association* is referred to as symbiosis, the legume plant in fact suffers an attack of the bacterium, which draws carbohydrates from it before it could fix atmospheric nitrogen and benefit the host. The productivity of the legume is an outcome of the whole association, and the microbiologists rightly “accuse” legume breeders of considering only a part of the whole system, the legume host, in their crop improvement efforts. Truly, the strong GxE interaction, so common in legumes, can be explained, at least in part, by the fact that the *Rhizobium* populations are very local in their characteristics so much so that a new improved variety developed in a certain place might not perform well in other places because of the difference in the bacterium population in the soil (Cubero and Nadal 2005).

Be that as it may, this fact only explains a small part of the yield lag when compared with cereals; the real reason may lie in the fact that the legumes have long been neglected in so far as research is concerned.

Problems and perspectives

The traditional problems in faba bean production are low yields, lack of improved varieties, poor mechanization, susceptibility to biotic and abiotic stresses, and nutritional constraints (presence of anti-nutritional or ‘non nutritional’ factors such as those causing favism) (Muzquiz et al. 2006). These factors not only affect humans but also diminish the productivity of farm animals. Although, in the modern animal husbandry the negative effects of nonnutritional factors are reduced because the legume flour is often mixed in low proportion with other ingredients, they are nevertheless a factor to be covered in plant breeding programs.

For making faba bean a more productive and economic crop, basic improvement is needed in adaptability, resistance to stresses, agronomic performance and nutritional value. Although still a great amount of work needs to be done, some significant advances have been achieved (general reviews on faba bean: Ávila et al. 2006; Cubero and Nadal 2005).

Spielman and Pandya-Lorch (2009) have recently shown that it is possible to succeed in trying to improve the performance of traditional farming materials and techniques when an integrated approach is adopted based on crop improvement, improved agronomic practices including conservation farming and improved access to marketing. In this connection, it would be necessary to remember the important role of legumes in maintaining and improving the soil physical and chemical properties. Legumes are the most important organisms fixing atmospheric nitrogen, an unlimited source of this basic element for living beings, by means of the symbiosis with rhizobia. The amount of fixed nitrogen depends on many variables, but the figures given below (in kg N/ha/year), drawn from various sources, show the significance of the symbiosis, especially in *sustainable agriculture* (Cubero and Nadal 2005): beans 12-215, chickpeas 24-84, faba bean 178-251, lentils 167-189 and pea 174-196. This fact has been very much neglected in modern farming at a time when there is an urgent need to reduce the use of nitrogen fertilizers because of environmental concerns, particularly because of their contribution to greenhouse gas emissions.

In terms of suitability for a sustainable farming system, faba bean can be used as a forage crop or as a green manure crop to increase the organic matter in the soil. Romans recognized this value of legumes. Columela, for example, commends them for establishing or restoring an old meadow; common vetches, lupins and faba beans were the most common ones for this purpose. In recent trials on forage production in Southern Spain, faba bean surpassed well known annual forage crops such as *Vicia sativa* and *V. narbonensis.*

The conclusion is that sustainable agriculture will be impossible without legumes, faba beans being among the best of them in N-fixing and in restoring or increasing the organic matter in the soil. This is even more important in developing countries and in arid zones.

Significant advances

In spite of the many constraints and the lack of continued research in the past, there have been many advances in research on faba bean in the recent times. New morphological types with useful agronomic characters have been obtained, some of them clearly valuable in arid and semiarid regions. Determinate habit cultivars show, besides an easy mechanical harvesting, a very much reduced poding period; the crop can use efficiently the winter and early spring water, producing the whole set of pods at once thus avoiding the usual spring dry period in these regions; determinate habit cultivars, although not resistant to or tolerant of drought, escape the unfavorable period (Nadal et al. 2001; Ávila et al, 2007). Other useful characters such as low tannin content or resistance to traditional diseases are being transferred to them by standard backcrossing programs.

Resistance to parasitic weed broomrape (*Orobanche crenata*) was identified by Egyptian breeders in the 1970s in the progeny of a cross between 'Rebaya 40' and the line 'F216'; the line F402 was produced in Egypt and crossed with the Spanish cultivar 'Alameda' to produce the cultivar 'Baraca' in Spain, whose level of resistance has proved to be very stable in several Mediterranean countries. Although susceptible to a different broomrape (*Orobanche foetida*), its level of tolerance to this new menace is superior to other sources (Cubero et al. 1992, 1999). Resistance to *Orobanche crenata* is of polygenic nature, but three stable quantitative trait loci (QTLs) have been identified and mapped, a fact that will facilitate the work of the breeders (Díaz et al. 2009 a). Molecular methods are available (including microchips), although not in such a standard way as in other crops, for DNA marker analysis (see extended reviews in Torres et al. 2006a, 2006b, 2009).

Genes for resistance to important diseases, rust (*Uromyces fabae*), ascochyta (*Ascochyta fabae*), chocolate spot (*Botrytis fabae)* are now known and studied. In the case of rust, there are at least two different systems of resistance, one of them being monogenic hypersensitivity, with molecular markers available for selection (Avila et al. 2003), the second one being of quantitative nature currently being studied. The study of two different sources of resistance to ascochyta have shown different QTLs stable across environments and genetic backgrounds as well as molecular markers linked to them (Avila et al. 2004; Díaz et al. 2009b). Studies on chocolate spot are still in progress, although two tolerant lines have been identified (Torres et al. 2006a, 2006b, 2010).

Non nutritional factors have also attracted attention and some progress has been made. Low tannin content is easily transferred as it is easy to identify by the white color of the flower; in fact, European cultivars have to be white-flowered, and the transfer is systematically performed to any new experimental promising line. To reduce the favism factors (vicine-convicine) to a non toxic level a morphological marker (white hilum) situated at 5cM (approximately) is successfully used. At least one cultivar ('Disco') shows both low-tannin and low-vicine-convicine contents (Duc

2006; Link 2006; Torres et al. 2006b, 2010). These advances are very important as they concern very traditional unfavorable characters, but there are other important advances worth mentioning. A consensus gene map is being built including molecular markers as well as 'true' genes (Elwood et al. 2008). The number and quality of molecular markers is increasing and, as a consequence, marker assisted selection (MAS) is in progress. Several QTLs concerning important characters (resistance to stresses, seed and plant features) are being identified and mapped to study their stability and the possibility of their use in assisting selection (Díaz et al. 2009; Torres et al. 2010). Although still in infancy, studies on gene expression and chromosome 'walking' are also in process (Torres et al. 2006a; 2010).

There is an active work on synteny as gene maps of different food legumes (pea, chickpea, lentil) as well as that of the model species for legumes, *Medicago truncatula* (whose genome has already been sequenced) are also available. Synteny is not only important from a theoretical point of view but also because of the possibility of devising new markers for a species based in the co-linearity of related species maps. Identification of candidate genes can also be another important consequence of studies on synteny. This approach has been as well undertaken in faba bean. A map anchored with orthologous markers mapped in *M. truncatula* was developed (Ellwood et al. 2008) allowing, for the first time, to establish macrosyntenic relationship between faba bean, *M. truncatula* and lentil. The additional development of a consensus gene map will be a reference tool for future use of genomic and genetic information in faba bean genetic analysis and breeding.

Although until now crosses between *V. faba* and postulated relatives have not been possible in spite of many attempts, widening the genetic base of the crop will be possible by using *paucijuga* forms (the closest to the hypothetical wild ancestor) and the knowledge of the process of domestication leading to *minor, equina* and *major* forms; the use of molecular markers will facilitate this study as most domestication characters are quantitative in nature (Cruz-Izquierdo 2009).

In vitro regeneration and transformation is also possible by *Agrobacterium* mediated transformation of *Vicia faba* embryo axes and *in vitro* grafting to avoid the risk of non functional roots of the transformed plant. The process is far from complete as the transformation efficiency is low (between 0.3 and 0.6%) and the whole process is time consuming (a total of 10-11 months is required). The efficiency has to be improved and many other important aspects (as for example the expression of transgenes) studied, but the door of that important process has been opened (Böttinger et al. 2001; Hanafy et al. 2005; Kiesecker 2006).

All these achievements show that although the lag when compared with leading world crops is very great, faba bean and some other pulses are no more at a 'cosmic' distance. Of course, the production potential of faba bean is still to be fully harnessed, but its yield could easily be doubled in most regions, as shown by the performance of modern improved cultivars grown with appropriate agronomic management. New determinate forms have been obtained and even if crosses with other species have been impossible up to now, there is a potential to transfer desirable traits from diverse sources through the possibilities opened by new biotechnologies.

While waiting for the perfection of new research approaches, using traditional plant breeding protocols and marker assisted selection (MAS) for disease resistance and quality traits can be the best approach for getting the desired materials in the shorter time in most countries.

Unexplored variability

There is still a huge genetic variation not yet used in breeding (Sadiki 2006). Leaves, seeds, pods, flowers, plant habits and cycles, etc. show a great variability. Low tannin content in white flowered lines is now well known, but the possibilities of so many colors in flowers and seeds remain to be studied. High yielding cultivars were obtained with little effort and low vicine/convicine content genotypes were identified in routine analysis of a germplasm collection. The same can be said of the genes for resistance to the main diseases.

Closed flower, allowing to obtain pure self pollinating cultivars avoiding the inconvenience of partial outcrossing, and leaf mutants, some leafless and semileafless as in pea (standard modern pea cultivars are semileafless), are known. The systematic mutation work by Sjödin in the 1950s has not been repeated although it proved very successful: many variants were produced, including the determinate habit gene and even the stock producing tetraploids and trisomics, so successfully used in mapping. In more recent times, mutants for *Rhizobium* nodulation were obtained, showing again the unexplored potential in the species.

Increasing the seed protein content while maitaining a high yield is well possible as the two characters are not correlated in faba bean. A protein content of up to 32% is feasible, although the main problem should be to maintain the lysine level, as legumes are rich in this essential aminoacid, compensating for relatively low level in cereals in animal feeding.

Heterosis is a demonstrated possibility. Hybrid varieties were obtained by French researchers after the pioneering work by David Bond in the 1960s; the genetic system underlying the character was studied and mastered after some basic research programs, although releasing hybrid cultivars was not possible because of the marketing difficulties. Synthetic cultivars are both easier to be produced and more convenient for developing economies; mathematical models to design them have been developed and thier efficiency proved in Spain and Germany (Maalouf 2001;Link 2006).

Drought tolerance is an essential character for faba bean adapted to arid or semiarid regions. Trials in Spain under natural conditions and in Germany under controlled ones (Arbaoui et al. 2006) show that there are cultivars and experimental lines showing the same yield under both dry and wet conditions, namely 'Alameda', 'Baraca', 'ILB 2282/1' and 'ILB 2282/2', and to a lesser degree 'ILB 938' and a Mediterranean cultivar, 'Enantia' (Link 2006). It is still a field to be further explored.

An unexplored areas worth mentioning unexplored area is the possibility of new uses of faba bean adding value to the product. Some other pulses, especially peas, are the base for prebiotics and nutraceuticals. Especially from soybean and pea, protein, starch, fiber, shakes, powders, even gel and films to heal the wounds have been produced and marketed in the USA and Canada. There is at least one commercial brand using faba bean. It is not 'food' in its classical meaning, but obviously the process is leading to added value.

Collaboration: a must

The success in faba bean research in the last 30 years was possible because of the effort placed on international cooperative programs.

An active program on faba bean improvement and management already started in the 1970s under the Nile Valley Project, led by ICARDA and the national programs of Egypt, Sudan and Ethiopia, was based on 'on farm trials' as a way to demonstrate *in situ* the advantage of new techniques and cultivars in the farmer's own field and under his/her supervision. After several ups and downs, the Nile Valley Project has been reactivated under a more ambitious program including the Red Sea and the Sub-Saharan Africa regions. The gap between the actual yield and yield potential is very large. Strengths and weaknesses have been identified by countries concerned in order to establish a coordinated action, thus providing an excellent example of international cooperation (Maalouf et al. 2009).

The late 1970s also saw the start of a fruitful cooperation between ICARDA on one side and the European countries on the other, which at that time had little connection among themselves. This cooperation resulted in many common meetings, projects and trials. Experience and materials were freely exchanged and the results were quick and promising; in fact, the base for new international projects was set up.

From the late 1980s up to now, several European projects were approved to undertake research on faba bean alone (CAMAR and EUFABA) as well as several related legumes along with faba bean (TRANSLEG and GLIP, the latter finished in 2008). The subjects ranged from classical breeding to molecular biology. These projects produced new materials, identified new genes, new knowledge, new methods and the feeling of belonging to one single but great team.

What can faba bean do for developing countries?

From the foregoing, several possibilities emerge that would be of value to the developing countries. Faba bean can help in (a) Producing a natural N-fertilizer for enriching soil; (b) Increasing the organic matter content in the soil; (c) Permitting crop rotations and crop diversification for sustainable farming; (e) Producing food, and dry and green feed; (f) Producing products of a greater nutritional value when used alone or blended; and (g) Permitting new functional applications. To sum up it would provide agricultural and health benefits. But in order to achieve these and other goals in the near future the only way forward is through integrated international cooperation.

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Policy approaches for coping with climate change in the dry areas

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Abstract

High levels of climate risk is characteristic of the dry areas of the developing world, but farmers there have developed extensive farming systems that enable them to survive shocks. Difficulties arise in that these systems are increasingly becoming inadequate to protect them against severe economic and human losses in major drought periods. The challenge is increasing as pressure on the available resource base increases because of population growth and there is increase in the frequency and duration of droughts because of climate change. To address these problems, many governments have intervened with various forms of drought assistance. However, many of these interventions are encouraging farming practices that could increase both the extent of future drought losses and the dependence of local people on government assistance. They are also costly to governments and use resources that could otherwise be spent for broader development purposes. This paper discusses important lessons from past policy approaches in the dry areas and develops criteria for guiding future policy and institutional choices. Particular attention is given to managing droughts and price spikes, and it is argued that while the public sector still has important roles to play, market assisted approaches, such as weather index insurance, should be more widely adopted.

Keywords: WANA region, dry areas, droughts, policy and institutional changes, price spikes, weather index insurance.

Introduction

High levels of climate risk have always been a defining characteristic of the dry areas of the developing world, and the agricultural and pastoral societies that inhabit them have developed extensive but robust farming systems that enable them to survive most weather shocks. Difficulties arise in that these extensive farming systems are increasingly becoming inadequate for meeting the rising livelihood expectations of local populations, and because the level of wealth accumulated in these societies is rarely adequate to protect against severe economic and human losses in major drought periods. The challenge is increasing over time as continued population growth adds to the pressure on the available resource base, and as climate change adds to the risk of more frequent and prolonged droughts.

To address these problems, many governments have intervened in dry areas with various forms of drought assistance. By buffering losses during droughts, it is hoped not only to alleviate human suffering but also to protect assets, especially livestock, and to encourage farmers to invest in agricultural intensification to raise living standards. However, many of these interventions are encouraging farming practices that could increase both the extent of future drought losses and the dependence of local people on government assistance. They are also costly to governments and use resources that could otherwise be spent for broader development purposes. This paper reviews past experience and explores policy options for improving the management of climate risk in dry areas.

The problem with climate risk in dry areas

Climate risk poses two major problems for farmers in dry areas. First is the high level of agricultural production risk that puts incomes, food security and debt repayment at risk each season. Second is the covariate nature of drought risk, leading to severe losses for many farmers at the same time.

To address these challenges, farm households and rural communities in dry areas pursue a number of strategies for managing risk. For example, to reduce their exposure to risk, farmers often spread their bets by growing a mix of crops and crop cultivars, staggering crop planting dates, spreading crops amongst fields that have different risk exposures in the landscape, and keeping livestock. These techniques can help reduce the chance of a major production loss in any one season. Many farm households also engage in off-farm employment, or have a small non-farm business of their own, and these help reduce their dependence on farm income. To cope with the losses that do occur, farmers carry food stocks, savings, and other assets (e.g. livestock and jewelry) that can be consumed or sold in times of need. They may also borrow credit and engage in temporary off farm employment.

Communities provide another layer of protection against risk. Religious funds, credit groups, and kin-support networks provide means through which individuals can help each other in times of need on a reciprocal basis. Sharecropping contracts also emerged in many societies as a way of sharing risks between landlords and tenants (Newbery and Stiglitz 1979; Otsuka and Hayami 1993). In pastoral areas, reciprocal arrangements between spatially dispersed communities enable mobile or transhumant grazing practices that reduce the risk of having insufficient forage in any one location (McCarthy et al. 1999).

Studies of traditional methods of risk management show they are surprisingly effective in handling most climate risks, and have helped farm families and rural communities survive for countless generations in many drought prone areas (e.g. Walker and Jodha 1986). But they are not without their costs and limitations. Diversification strategies prevent farmers from specializing in their most profitable alternatives, essentially trading off higher income to reduce risk exposure. Studies of drought-prone areas in India and Burkina Faso suggest that farmers may sacrifice 12-15% of average income to reduce risk (Gautam et al. 1994; Sakauri and Reardon 1997). Farmers may also be less willing to invest in agricultural intensification if this is more risky, leading to additional long term sacrifices in living standards.

Traditional risk management arrangements frequently fail to provide an adequate safety net for the poor. With few assets, poor people have limited options for coping with serious income losses. They are also more exposed to food price increases that may follow local production or market shortfalls, and they are more exposed to any contraction in local employment and wages. There is a growing literature showing that repeated income shocks and asset losses can conspire to keep poor households trapped in poverty. Credit, which might offer a viable pathway out of poverty, is also much less likely to be available to the poor (Carter and Barrett 2006).

Perhaps the greatest weakness of traditional risk management in dry areas is its limited ability to manage catastrophic droughts that impact on most farmers within a region at the same time.

The highly covariate nature of these losses makes them especially difficult to manage. Community support networks cannot cope when everybody needs help at the same time. Credit also becomes scarce when everybody is seeking to borrow and few have money to lend. Local markets for crops, feed and livestock also work against farmers when they all are trying to trade the same way at the same time. For example, because many farmers try to sell livestock in drought years they force animal prices down, and then when they try to restock in post-drought years, prices shoot up. Local food prices can also spike when regional shortages arise, and many farmers may lose important assets (e.g. livestock) that make subsequent recovery slow and difficult. Covariate risks are also a problem for financial institutions and input suppliers, since they can be faced with widespread defaulting on loans and unpaid bills. Some of the most dramatic evidences of the failure of traditional risk management arrangements in handling covariate risk come from studies of drought. For example, detailed studies of the impact of droughts in Ethiopia (Webb and von Braun 1994), Eastern India (Pandey et al. 2007) and South India (Hazell and Ramasamy 1991) all show that in percentage terms, income losses can far exceed initial production losses because of a collapse in local agricultural employment and wages, nonfarm income and asset prices. Most households in drought hit areas suffer consumption shocks with the impact being most severe for the poor. In pastoral areas, droughts can also lead to liquidation of a significant share of the total livestock in the absence of other sources of feed (Hazell et al. 2003).

Lessons from past policy interventions

Recognizing the limitations of traditional risk management, many governments have intervened in dry areas with a range of risk management programs for farmers and herders, including crop insurance, credit forgiveness, livestock feed subsidies, and emergency relief. These are reviewed below.

Crop insurance

Crop insurance has often appealed to policy makers as an instrument of choice for helping farmers and agricultural banks manage climate risks like drought, but the experience has generally not been favorable (Hazell et al. 1986; Hazell 1992). Publicly provided crop insurance has, without exception, depended on massive subsidies from government, and even then its performance has been plagued by the moral hazard problems associated with many sources of yield loss, by high administration costs, by political interference (especially of compensation payments in election years!), and by the difficulties of maintaining the managerial and financial integrity of the insurer when government underwrites all losses (Hazell 1992). Livestock insurance that compensates for loss of animals or reduced productivity because of drought has rarely been offered, and seemingly not at all for herders in traditional pastoral systems. There are good reasons for this: the incidence of drought losses is usually too high to make the insurance affordable, opportunities for fraud and moral hazard are too great, and there is little opportunity for on-farm inspection of management practices or loss assessments, particularly when the animals are on the move.

Public crop insurance programs became hugely expensive to governments and most of the programs in developing countries have now been phased out. Private crop insurance has since grown in some countries, but to avoid the pitfalls of the public programs, private insurers typically only offer contracts against specific perils (e.g. hail or frost damage) and sell mostly to commercial farmers growing higher value crops. Private crop insurance rarely reaches into dry areas or covers general drought risk.

Feed subsidies

Feed subsidies have been an important public intervention for managing drought risks in countries with significant pastoral farming systems. In the West Asia and North Africa (WANA) region, feed subsidy programs have been widely used to provide supplementary feed to safeguard livestock in drought years, with the predominant expenditure going for subsidies toward the costs and distribution of concentrates and other feeds, especially barley (Hazell et al. 2001). These programs have been quite successful in protecting livestock numbers and production during droughts, but they have also encouraged unsustainable farming practices and have benefited large herders rather than small. In particular, they have:

- Accelerated rangeland degradation in the long term by undermining the traditional process of adjusting flock size to inter-annual climatic variations. Herd sizes have increased sharply since the introduction of feed subsidies, and grazing practices have changed so that many of the animals no longer leave the rangeland areas during the dry season but have their feed and water trucked in. This practice leads to overgrazing during the dry season, reduces the natural seeding of annual pasture species, disturbs the soil, and contributes to wind erosion, particularly in areas near water and feed supply points.
- Led to high government procurement prices for barley that has encouraged the mechanized encroachment of barley cultivation onto rangeland areas where it causes serious soil erosion and cannot be sustained.
- Aggravated income inequalities in dry areas because the subsidies are typically administered on a per animal or per hectare basis and large herders and cereal farmers have captured most of the payments.

Feed subsidies, although typically introduced as a relief measure in severe droughts, once established have tended to become permanent and expensive to governments. Total costs became high and they were scaled back in most countries as part of market liberalization programs of the 1990s.

[1] Hazel (1992) analyzed the experience with public crop insurance programs in seven countries with five or more years of available financial data and found that the total payouts exceeded the premiums collected from farmers by a factor ranging from 2.4 to 5.7 (i.e. governments had to subsidize 40-80% of the total cost). The total cost to governments ranged from $10 (USA) to $408 (Japan) per insured hectare in 1987 prices.

Relief programs

Many governments have found it necessary to provide direct disaster assistance to relieve the problems of rural areas stricken with catastrophic losses caused by natural hazards such as drought, floods, hurricanes. For many small, risk prone countries, such government assistance can be extremely costly and may represent a significant percentage of national income when the disaster is large. This cost detracts from the resources available for agricultural development, and increases a country's dependence on donor assistance. These costs may escalate in the future as population densities increase in vulnerable areas and as global climate change increases the frequency and severity of some kinds of natural disasters.

Relief programs are driven by humanitarian rather than development agendas and their primary value is in saving lives and rebuilding assets and livelihoods. However, they have run into a number of problems (see for example Grosh et al. 2008):

- It is difficult to target relief aid to the truly needy under emergency conditions and large leakages to others are common.
- Relief can distort incentives for development e.g. food aid can depress local prices for farmers.
- By the time an emergency has been declared and a relief effort funded and launched, the assistance often arrives too late to help the truly needy.
- Once disaster assistance has been institutionalized and people know they can count on it, it has many of the longer term effects of an insurance subsidy that inadvertently worsens future problems by encouraging people to increase their exposure to potential losses. For example, compensation for flood or hurricane damage to homes can lead to the building of more houses in flood and hurricane prone areas. Similarly, compensation for crop losses in drought prone areas encourages farmers to grow more of the compensated crops even when they are more vulnerable to drought than alternative crops or land uses.

Some general lessons

A common problem with many public risk management interventions is that they lead to moral hazard problems and people may not take reasonable precautions to prevent or minimize losses. This is most obvious in the case of multiple-risk crop insurance, but similar disincentive problems have arisen with livestock feed subsidies and public relief programs.

Once they are entrenched, sustained subsidies for risk management interventions can distort economic incentives. Subsidies for risk management have similar effects as subsidies on any other input; they encourage over use of that input. In this case the "overuse of the input" is the adoption of farming practices and livelihood strategies that lead to a growing dependence on government assistance. For example, compensation for crop losses in drought prone areas encourages farmers to grow more of the compensated crops.

Governments have tried to manage too much risk. It is simply too costly to try and underwrite all the production fluctuations confronting farmers and rural communities. Many of these risks are too open to moral hazard and asymmetric information problems and occur with too high a frequency to be insurable at reasonable cost. Most households and rural communities have already proved that they are quite capable of managing independent risks and small covariate risks. It is the catastrophic risks in the lower tail of the loss distribution that are more problematic and need to be addressed, such as severe or back-to-back droughts in dry areas.

Policy options for improving risk management in dry areas

Recent years have seen institutional, market and technological advances that have increased the range of policy options available for assisting farmers and rural communities manage droughts in dry areas. Some of these approaches are market based and do not require direct government interventions. Specifically, we look at the following options:

- Strategies to reduce exposure to drought losses.
- Promotion of weather index insurance for better management of weather risks.
- Promotion of early warning drought forecasting to better prepare farmers for impending droughts.
- Strengthen safety net programs.

Invest in reducing exposure to drought risk

There are a number of investments that can reduce farmers' exposure to drought losses. These options include investing in physical structures and wells to increase irrigation and water supplies, contouring land or planting vegetative bunds to improve water capture in soils, and planting drought-resistant shrubs in grazing areas. These actions need not all be financed by government. In some cases, simply strengthening property rights over cropland or providing long-term credit may provide sufficient incentive for farmers to make their own private or community investments. Public investments in agricultural research can also be targeted toward developing more drought-tolerant crop varieties and livestock breeds, thereby reducing yield losses in drought years. Recent developments in biotechnology offer exciting new possibilities in this respect. Improvements to rural roads can broaden the reach of local markets, helping to move livestock and feed over wider areas in the event of drought and buffering potential price fluctuations. Investments in education and health can increase opportunities for out-migration from dry areas. Many of these investments are win-win strategies that improve average farm productivity while also reducing exposure to drought losses.

Weather index insurance

Weather index insurance is an attractive instrument for managing the kinds of covariate drought and flood risks that local communities cannot manage on their own.

The essential principle of this kind of insurance is that contracts are written against specific perils or events like droughts, which are defined and recorded at regional levels, usually a local weather station. To serve as agricultural insurance, the index should be defined against events that are highly correlated (on the downside) with regional agricultural production or income. For example, an insured event might be that rainfall during a critical period of the growing season falls 70% or more below normal.

All buyers in the same region are offered the same contract terms per unit of insurance coverage. That is, they pay the same premium rate and, once an event has triggered a payment, receive the same rate of payment, and their total payments and indemnities would be that rate multiplied by the value of the insurance coverage purchased. Payouts for index insurance can be structured in a variety of ways, ranging from a simple zero/one contract (once the threshold is crossed, the payment rate is 100 percent), through a layered payment schedule (e.g., a one third payment rate as different thresholds are crossed), to a proportional payment schedule.

Advantages: Area-based index insurance has a number of attractive features:

- Because buyers in a region pay the same premium and receive the same indemnity per unit of insurance, it avoids perverse incentive problems. A farmer with regional index insurance possesses the same economic incentives to produce as profitable a crop as the uninsured farmer.
- It can be inexpensive to administer, since there are no on-farm inspections, and no individual loss assessments. It uses only data on a single regional index, and this can be based on data that is available and generally reliable. It is also relatively easy to market.
- The insurance could in principle be sold to anyone. Purchasers need not be farmers, and the insurance could be attractive to anybody in the region whose income is correlated with the insured event, including agricultural traders and processors, input suppliers, banks, shopkeepers, and laborers.
- As long as the insurance is voluntary and unsubsidized, it will only be purchased when it is a less expensive or more effective alternative to existing risk management strategies. If the insurance is offered in small denominations it may also appeal to poor people.
- Recent developments in micro-finance make area-based index insurance an increasingly viable proposition for helping poor people better manage risk. The same borrowing groups established for microfinance could be used as a conduit for selling index insurance, either to the group as a whole, or to individuals who might wish to insure their loans

Challenges: Index insurance faces a number of challenges. One is generating sufficient demand for a sustainable insurance market to emerge. Clearly, the greatest potential will lie in regions where weather related risks are the dominant risks confronting farm households. Index insurance also needs to be affordable compared to viable alternatives for managing risk. If the probability of the insured event is too large, then the premium rate can become prohibitive in the absence of a subsidy. As a practical rule of thumb, events that occur more frequently than 1/7 may be too costly for most farmers to insure without a subsidy.

Basis risk can also be a deterrent to demand. This is the problem that arises if an individual suffers a loss but is not paid because the major event trigging a payment for the region has not occurred. For example, an individual farmer with rainfall insurance could lose her crop to drought, but not receive an indemnity if the drought is not widespread and recorded at the region's weatherstation [2]. With index contracts it is also possible for an individual to be paid when they suffer no losses. The insurance will not be attractive to farmers if the basis risk becomes too high.

Basis risk can be reduced by limiting the insurance to covariate weather events that affect most people in a region. Individual losses are then much more likely to be highly correlated with the insured weather station event. Another way to reduce basis risk is to increase the number and dispersion of weather stations so as to better capture spatial variation in climatic conditions in writing contracts. Technological advances are rapidly reducing the cost of adding secure weather stations, and in some countries private firms now offer weather station services for a fee (e.g. India). A bigger problem is that new weather stations come without site specific historical records. This has led to interest in new types of indices that can be assessed remotely with satellites, such as cloud cover or soil moisture content for a chosen region during critical agricultural periods, and which can be triangulated against existing weather data station. This kind of data is becoming increasingly available and may prove the wave of the future. Another problem is that other government interventions like subsidized crop insurance, bank credit guarantees or relief programs can crowd out demand for index insurance.

Yet another challenge for the insurer is the highly covariate nature of the payouts. This is because all those who have purchased insurance against the regional index must be paid at the same time. The insurer can hedge part of this risk by diversifying its portfolio to include indices and sites that are not highly and positively correlated, an approach that works best in large countries. Most often it is also necessary to sell part of the risk in the international financial or reinsurance markets. One of the key drivers of index insurance today is the growing depth and diversity of these markets for absorbing some kinds of natural disaster risk (Skees 1999, 2000).

Experience: The concept of index insurance is not new but until recently the most common form of index insurance available has been area-yield insurance. In this case, the index is the average yield of a county or district as recorded by government agencies through randomized crop yield measurements. Programs exist in the US, India, Sweden, and the Canadian province of Quebec (Miranda 1991; Mishra 1996; Skees et al. 1997). All are heavily subsidized with substantial public sector involvement.

Over the past five years, a plethora of weather index programs have been launched around the world, with the active engagement of a diverse range of actors including governments, multinational agencies, private insurers, international reinsurers, relief agencies, NGOs, banks, input suppliers, food marketing companies, and farmer organizations. Recent reviews by the International Research Institute for Climate and Society at Columbia University (Helmuth et al. 2009) and the International Fund for Agricultural Development and the World Food Programme (IFAD/WFP, forthcoming, 2010) found 29 ongoing weather index insurance programs for farmers around the world with a total insured value of about $1 billion in 2008/9 and reaching some 1.2 billion farmers.

Some 60% of the total coverage was written in OECD countries, mostly the US, and the rest was written in developing countries (mostly India). Most programs insure against regional estimates of drought or excess rainfall. In Mongolia, a program insures herders against winter livestock losses using regional livestock census data collected each year by the government.
Although it is still early to evaluate most of these programs, the IFAD/WFP study identified some important lessons. These include:

[2] A good low-cost weather station with automatic capabilities costs about US$2,000. They cost even less in India.

- *Distinguish between social and development objectives.* Some schemes are designed to help poor people protect their livelihoods and assets, and are primarily an alternative to more traditional types of relief or safety net programs. Other schemes are designed to help farmers with viable businesses manage their risks (both income and asset losses). Insurance that protects the livelihoods and assets of poor people from catastrophic losses inevitably has to be subsidized, and is best delivered through channels that are aligned with safety nets rather than development interventions (e.g. NGOs and public relief agencies). On the other hand, insurance that promotes agricultural development should be channeled through financial or private intermediaries, and can often sell on an unsubsidized basis.Mixing these two needs in the same program all too easily leads to insurance products that have to be heavily subsidized for all, and which serve social rather than development objectives.

- *Focus on a real value proposition for the insured.* Insurance products for development purposes are unlikely to be attractive to farmers without subsidies if they merely substitute for existing risk management practices. On the other hand, insurance products that catalyze access to credit, technology, or new markets and help generate significant additional income can be attractive, even without subsidies. But the additional income created must be substantial, not just enough to cover the insurance premium. Products must be affordable and cover the most relevant risks with minimal basis risk, and there must be opportunities to finance the premium with credit. Of the 29 programs reviewed by IFAD/WFP, 18 operate without any subsidies.

- *Develop efficient delivery channels.* Insurers rarely have their own rural distribution networks and typically must rely on intermediaries to sell and transact the insurance with farmers. These intermediaries need to be efficient providers, and available and responsive to farmers' needs. They also need to be trusted, as must the insurance company itself. Ongoing programs are successfully using microfinance institutions, banks, fertilizer distributors and marketing agents as intermediaries.

- *Access international risk transfer markets.* Reinsurance support is essential for attracting private insurers and scaling-up. Reinsurance can also be a business driver, because reinsurers are ready to write up to 99% of the risk [3]. This allows insurers to earn commissions without tying up capital – unlike typical insurance business where reinsurers require retention levels of at least 15% of the risk to avoid moral hazard. Of the 29 farm programs reviewed by IFAD/WFP, 18 are reinsured internationally.

- *Provide adequate and early training of all implementation actors.* Index-based insurance programs that include initial training and an overall approach to capacity development have a clear advantage compared to those that do not. By training farmers in the use of index insurance as a risk reducing investment, more realistic expectation about payments can be achieved, as well as an increased familiarization with the nature of the product.

In nearly all the cases reviewed by IFAD and WFP, private insurers were engaged but did not initiate the programmes. This suggests there is a first mover problem: the high initial investment costs in research and development of index insurance products might not be recouped, given the ease with which competitors can replicate such products if they prove profitable to sell. Private insurers may be particularly wary of this issue; unlike public insurers, they are not subsidized and may miss the opportunities that public insurers have as early movers.

The IFAD/WFP study identifies several areas on public intervention that may be needed if index insurance is to scale up:

- Build additional weather station infrastructure and data systems.
- Support agro-meteorological research leading to product design.
- Provide an enabling legal and regulatory environment.
- Educate farmers about the value of insurance.
- Facilitate initial access to reinsurance.
- Support the development of sound national rural risk management strategies that do not crowd out privately provided index insurance.

[3]The objective third party settled nature of the weather index insurance product makes the 99% reinsurance levels possible.

Early warning drought forecasts

In principle, the ability to provide early warning drought forecasts could be a powerful tool for avoiding many of the problems that arise because farmers, herders, and other decision makers must commit resources each year before key rainfall outcomes are known. For example, decisions about planting crops (such as date of planting, seeding rate, and initial fertilizer treatment) often have to be made at the beginning of the rainy season before knowledge about rainfall outcomes is available. The economic value of season-specific forecasts depends on the degree to which farmers can adjust their plans as the season's rainfall unfolds. Of course, the reliability of the forecasts and the ability of the farmers to adjust their initial decisions in response to this information are also critical. If decisions about planting and cultivation practices and the feeding, culling, and seasonal movement of livestock can be sequenced, with key decisions being postponed until essential rainfall data are available, then forecast information will be less valuable. But if most decisions must be made up front each season, then the scope for mistakes will be much larger and the potential economic gains from reliable forecast information will be greater. Stewart (1991) examines how the date of onset of the rainy season can provide a fairly reliable forecast of the ensuing seasonal rainfall pattern for Niamey, Niger, and shows how this information could be used to more optimally adjust planting and input decisions for the season (this is his "response" farming approach). Barbier and Hazell (1999) use a farm model to show how many of the decisions in a typical agro-pastoral community in Niger can be optimally adjusted to rainfall outcomes.

Reliable drought forecasts could also enable governments and relief agencies to position themselves each year for more efficient and cost-effective drought interventions. This possibility has already been realized, and several early warning drought systems now in place in Africa have proved successful in giving advance notice of emerging drought situations. But these programs are really monitoring systems that track emerging rainfall patterns within a season rather than true weather forecasting systems that predict rainfall outcomes before they even begin.

Reliable multiyear rainfall forecasts are not yet possible, but seasonal forecasts (from three to six months out) have become more reliable, particularly where an important part of the year-to-year variation in seasonal rainfall can be attributed to the Pacific El Niño Southern Oscillation (ENSO) weather patterns. As the ability to model these phenomena at the global and regional levels improves, it seems plausible to expect that more reliable seasonal forecasts will be available at local levels. Private weather forecasting services may expand and become more available to developing countries. But this is also an area where government could play a catalytic role, and even subsidize many of the development costs, without having to worry that this involvement would distort resource management incentives at the farm level.

Non-agricultural safety nets

A very different policy approach is for governments to reduce or withdraw from providing direct support to agriculture in drought years and to focus instead on providing efficient and well-targeted safety net programs that ensure all needy people have adequate access to food and other essentials, including in drought years. Recent developments in the design and implementation of safety net programs can make this approach more cost effective and better targeted than in the past (Grosh et al. 2008). It would, however, probably lead to a shift toward more extensive farming systems in the dry areas, with a reduced capacity to support the existing rural population in agriculture.

Weather index insurance can also be used by relief agencies to improve their capacity to respond to natural disasters. The relief agency could use the insurance in two ways. One would be to retain the insurance payouts and use them to directly fund its own relief efforts. Alternatively, the relief agency would distribute insurance vouchers each year to targeted households who could then cash them in during an insured emergency and use the funds for their own discretionary purposes. In practice, some combination of these two options may be best.

The main advantage of index insurance for relief purposes is that it can provide timely and assured access to funds in the event of an insured catastrophe. Studies show that the earlier relief arrives after a shock, the greater its effectiveness in cushioning adverse welfare impacts, avoiding the distress sale of assets and speeding up recovery (e.g. Dercon 2005). By selecting a weather-based index that is an early or lead indicator of an emerging crisis, an insurer can make quick payments to relief agencies and households, avoiding the usual delays incurred when relief agencies must first appeal for donations from governments and donors before addressing the crisis.

Using insurance for relief purposes also has implications for the way relief is funded. Instead of ad-hoc fund raising after emergencies occur, the financial needs of relief agencies are annualized into an insurance premium. Governments and donors then face a predictable annual contribution that can be easier to budget.

Conclusions

Risk has long been an important constraint to food security and agricultural development in the dry areas, and there is already an existing deficit in the institutional and policy arrangements for managing covariate risks like drought. Moreover, many past interventions have encouraged farming practices that increase both the extent of future drought losses and the dependence of local people on government assistance. They have also proved costly to governments. Climate change seems likely to add to these problems if the frequency and severity of droughts increases.

There are better alternatives for assisting farmers and rural communities manage their risks. The most promising are: direct investments in watershed management and agricultural research to reduce potential losses during drought years; weather index insurance, seasonal weather forecasts, and more effective safety net programs.

The public sector has key roles to play in either financing key investments (e.g. watershed development and agricultural research, or subsidizing relief programs) and in creating a supportive environment for market assisted development (e.g. weather insurance and weather forecasting). For many countries this will require a reform of existing policies towards risk management in dry areas, but ones that will be necessary if public resources are to be used more effectively in adapting to climate change.

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Rethinking agricultural development of drylands: Challenges of climatic changes

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Abstract

Development of the dry lands faces several challenges. Among these, climatic change and increasing land degradation are the most serious. The impact of local climatic change or long-term climatic variation on the dryland resources is an issue that needs attention. Another issue of greater concerns is the uncertainties associated with future projected impacts of global warming, at local scale, and the inability to distinguish its impact from local degradations leaving planners and decision makers with confusion, which reduces their ability to select approaches to protect or develop dryland resources. Development has site specific requirements, and implementation has to consider local as well as regional and global drivers. Thus, decision makers and users alike have to deal with many interrelated issues. Adaptation of dryland farming systems to address theses issues, at a scale from global to local requires fresh approaches including new policies, better governance, innovative research, technological tools, as well as stronger well coordinated regional and international efforts. This paper addresses the impacts of global warming and land degradation on the dryland agricultural resources with special focus on Mediterranean and North African region. New approaches, opportunities, paths of development, strategies, researches, and modern technological tools needed to adapt or mitigate the impacts of climate change and land degradation on drylands resources are discussed.

Key words: dry land, global warming, climate change, land degradation, adaptation, mitigation.

1. Introduction

The world's drylands represent more than 40% of the global land area and are home to nearly a third of the global population, 90% of which lives in developing countries (Zafar et al. 2005). Agriculture remains fundamental for poverty reduction, economic growth and environmental sustainability. Land resources here have a primary role in providing food and fiber for increasing population and as 82% of total agricultural land area is rainfed, its importance is substantial (Swallow and Noordwijk 2009).

Development of the drylands faces several challenges. Among these are: (1) Climatic change and increasing land degradation, (2) Increasing needs for food production to meet the rising population demands, (3) Low productivity, (4)Vulnerability of local population, (5) Shift from food production to bio-fuel production, (6) Increasing cost of energy, (7) Shortage of land and water resources, (8) Impact of globalization and market liberalization, (9) Poor governance and lack of sustained strategies, (10) Lack of skilled human resources and poor research capability, (11) Increasing level of forced migration, and (12) Marginalization of rural inhabitants. Climate change will have dramatic consequences on agricultural production in dry areas. Water availability will become more variable, droughts and floods will inflict additional stress on agricultural systems, some coastal food-producing areas will be inundated by the seas, and food production will fall in some places in the interior. This paper focuses on pressures inflicted on drylands resources by climate change and research and developmental efforts needed to adapt or mitigate these effects.

2. Climatic change vs. variation

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period, typically decades or longer. According to the United Nations Framework Convention on Climate Change (UNFCCC) climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is, in addition to natural climate variability, observed over comparable period of time (UNEP 1999). This definition makes a distinction between 'climate change' that is attributable to human activities altering the atmospheric composition of the globe and 'climate variability' attributable to natural causes. According to UNCCD, desertification is attributed to anthropogenic drivers and climatic variations (UNEP 1996), but without clear distinction between short-term and long-term variations. Soil, as a part of ecosystem, interacts directly and indirectly with both types of climatic variations. Each type could cause different types of changes to the soil system. Understanding the causes and influences of both types of climatic changes on the soil system is very important for designing adaptation or mitigation activities.

3. Anthropogenic climatic changes

Examination of soil properties, which can be attributed to climatic changes, revealed that specific changes in soil properties could not be the results of short-term climatic changes attributed to global warming, but rather to the long-term naturally occurring climatic changes (Taimeh 1984). The extent and impact of the second type of changes, which could cause desertification, are not very well assessed due to the absence of regional field investigations. As a matter of fact, most of the available assessment about such changes was based on personal opinions, not quantitative assessments (Dregene and Chou 1992; Nasr 1999).

While climatic variation and human activities have been recognized as the main cause of land degradation, the global climate change is attributed to human activities such as demographic, economic, sociopolitical, and technological and behavioral changes of the people such as changes in land use and deforestation, which have resulted in increased emission of Green House Gases (GHG).

The global atmospheric concentration of CO_2, the most important anthropogenic GHG, has increased from a pre-industrial value of 280ppm to 379ppm in 2005 (IPCC 2007a), primarily due to fossil fuel use and to a lesser extent by the land use changes.

Methane (CH_4) and nitrogen dioxide (N_2O) concentrations are primarily being enhanced due to agriculture (IPCC 2007b). The contribution of agricultural land to global annual GHG emissions is14% and that of the land use change (including forest loss) is 19 %. The developing world accounts for about 50% of agricultural emissions and 80 % of land use change emissions (IPCC 2007b). Agriculture contributes more than half of the world's emissions of CH_4 and N_2O. N_2O is produced by microbial transformations of nitrogen in the soil under both aerobic and anaerobic conditions. CO_2 fluxes between the atmosphere and ecosystems are primarily controlled by uptake through plant photosynthesis and releases via respiration and the decomposition and combustion of organic matter. Agricultural management activities modify soil carbon (C) stocks by influencing the C fluxes of the soil system (Bruce et al. 1999; Ogle et al. 2005; USEPA 2006a).

4. Projected climatic changes

According to the IPCC first short-term projection assessment (IPCC 1990) the global average temperature was projected to increase between about 0.15 and 0.3°C per decade from 1990 to 2005. The actually observed values of about 0.2°C per decade strengthened the confidence in the short-term projections. Projections of future changes in climate for the next two decades, under a range of emissions scenarios, suggested a warming of about 0.2°C per decade. Even if the concentrations of all GHG and aerosols were kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. It is also worth noting that scientists did not however, rule out the possibility that other natural forces may be playing a significant role (Zafar et al. 2005).

5. Impacts of global warming

According to IPCC (2007b), as a result of global warming, global sea level rose at an average rate of 1.8 mm per year over 1961 to 2003 (3.1 mm per year from 1993 to 2003). Over the period from 1900 to 2005, precipitation declined in the Sahel, the Mediterranean region, Southern Africa and parts of Southern Asia. Globally, area affected by drought has increased since 1970s. Extreme weather events have increased in frequency and/or intensity over the last 50 years. Cold days, cold nights and frosts have become less frequent over most land areas, while hot days, hot nights and heat waves have become more frequent.

The frequency of heavy precipitation events, or proportion of total rainfall from heavy falls, has increased over most areas. Recent warming is strongly affecting terrestrial biological systems, including changes such as earlier timing of spring events such as greening of vegetation. Projected changes in climate for the twenty-first century will occur faster than they have in at least the past 10,000 years. Combined with changes in land use, increasing losses of species from ecosystems, and the spread of exotic or alien species, are likely to limit both the capability of species to migrate and their ability to persist. By 2025, two-thirds of the earth's population will suffer water shortages, and by the year 2080, an extra 1.8 billion people could be living without enough water.

It is important to note that climate change might also give rise to new opportunities. For example, changes in temperature and precipitation regimes, especially at high latitude regions might make it possible to grow food crops at new locations, potentially contributing to increased food security.

5.1. Specific impacts of global warming on systems and sectors

The exact impact of GHG emission is not easy to forecast when it comes to predictive capability of employed models, especially at local scale. Furthermore, the relationship between climatic and anthropogenic factors causing desertification is a rather complex issue that local planners have to face. Desertification adds to the complexity since it contributes significantly to climate change and biodiversity loss, which in turn, is considered to occur due to climatic change or variability.

Furthermore, the impact of climatic variability and climate change may not be easy to distinguish from one another, due to uncertainty associated with the future trends of both. Nevertheless, following is a brief summary of some important impacts attributed to global warming, particularly, relevant to dry lands.

Impacts on ecosystems: The resilience of many ecosystems is likely to be stressed beyond the limit this century by an unprecedented combination of climate change and associated disturbances. With increases in global average temperature of 1.5 to 2.5°C, there will be major changes in ecosystem structure and function, species' ecological interactions, and shifts in species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services. Approximately 20 - 30% of plant and animal species assessed so far, are likely to be at increased risk of extinction. There will be increases in the rate of erosion, accelerated loss of wetlands, and seawater intrusion into freshwater sources as a result of increases in flooding adding to desertification.

Impacts on food production: Higher temperatures, more variable precipitation, and changes in the frequency and severity of extreme climatic events will have significant consequences on food production and food security. The degree of reduction in the productivity will depend on the adaptive capacity of farmers, which creates another uncertainty in predicting damages (Reilly et al. 1994). At lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1 to 2°C), which would increase the risk of hunger.

5.2. Uncertainty associated with climate change

Scientists have faced difficulties in simulating and attributing observed temperature changes to their impacts at small scales because at that scale natural climate variability is relatively larger, making it harder to distinguish expected changes due to external factors. Uncertainties regarding the impacts of local factors, such as those due to aerosols and land-use change, and feedbacks also make it difficult to estimate the contribution of global GHG increases to observed small-scale temperature changes (Corell 2006). It is to be noted that many projections indicated above are still challenged by many scientists (US Congress 2009). This is due to the complexity of the global climate and inability of employed global climate models to project changes at smaller scales. Limitations and gaps currently prevent more complete attribution of the causes of observed natural system responses to anthropogenic warming. The available analyses are limited by the number of systems, length of records, and locations considered. Natural temperature variability is larger at the regional than the global scale, thus affecting identification of changes to external forcing. At the regional scale, other non-climate factors, such as land-use change, pollution and invasive species, are influential (IPCC 2007c). Regional changes in climate are therefore expected to be much more pronounced than changes in the global average (Alley et al. 2003). Furthermore, the IPCC predicts that changes in rainfall will vary greatly around the world, with rainfall increasing in high-latitude regions but decreasing in other regions (IPCC 2007c). Major scientific uncertainties associated with predictions of climatic changes and its impacts complicate any assessment of the benefits of policies to reduce climate change.

6. Desertification

The issue of desertification, or land degradation, is very important for the development of drylands. The relationship between global warming and desertification is rather complex. Nevertheless, the policy makers have to deal with specific impacts at specific locations before formulating specific adaption or mitigation measures. Unfortunately, projections based on global warming scenarios are not of much help here.

Some researchers consider desertification to be a process of changes, while others view it as the end result of a process of changes (Glantz and Orlovsky 1983). This distinction represents one of the main areas of disagreements concerning the concept of desertification. When considered to be a process, desertification has generally been viewed as a series of incremental changes in biological productivity in arid, semi-arid, and sub humid ecosystems. When considered as an end result, desertification refers to the prevalence of desert-like conditions in an areas that once was green. Desertification and stresses in marginal drylands are caused by a combination of direct and indirect drivers. Direct drivers are natural processes such as droughts and indirect drivers are human interventions at the local level such as inappropriate irrigation systems, deforestation, overgrazing, and land cover and quality changes through change in land use (Geist and Lambin 2004). Use of agricultural practices unsuited to marginal drylands has led to degradation of land and water.

According to an estimation by The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD 2004) only 11% of the total area of Middle East and North Africa (MENA) region can be used for rainfed farming systems (annual rainfall more than 400mm). These areas however suffer from severe land fragmentation, which exacerbates soil erosion. Rangelands occupy 472 million hectares or 33% of the total area. Desertified land (problematic soil) occupies about 9.8 million square km, while that threatened by current desertification covers about 2.86 million square km. The degree and type of desertification varies from one country to another within the region.

Contribution of climatic change to desertification could be viewed from three different angles: (a) anthropogenic-induced climatic changes, (b) natural short-term climatic variation, and (c) long-term gradual climatic changes. The last type requires further attention since some local studies provided evidence indicating a leading role of natural climatic change in causing desertification. Such type of climatic change did not receive proper attention partly due to lack of local or regional studies. Field investigations in Jordan have provided definite information that substantiates the role played by gradual climatic changes as a primary driver causing desertification. Evidence of the role of gradual climatic changes is clearly demonstrated by the changes in the soil system in Jordan (Taimeh 2009). The presence of well-developed soils, whose current properties could never be explained on the bases of the global warming that started with the onset of the industrial era, is a reflection of the gradual climate changes. An examination of the rainfall patterns during the last 60 years indicates a pattern of clear reduction in annual rainfall within different ecological zones in Jordan (Table 1). Reduction in the annual precipitation is also associated with seasonal variations. The examination of soil properties development pattern, which would reflect a clear impact of gradual climate changes over long period, revealed that such rainfall trend must have been occurring for a period longer than the time which marked the beginning of global warming.

Detailed field investigation, conducted at various locations in Jordan, revealed the presence of soils that developed under a sequence of humid-dry climate, and currently under the influence of dry conditions all over the country (Taimeh 2009).

This wide occurrence of such soil sequence was confirmed even within areas classified as sub-humid, where the status of soil properties represent an initial stage of changes that can be termed as incipient desertification. The overall assessment of soil developmental pattern clearly suggests that

Table 1. Annual reduction in the average rainfall in last 30 years as compared to the average of 30 years prior to that period in different rainfall zones in Jordan

Station & rainfall	Last 30 years	30 year earlier	% Reduction per year
100-200 mm			
Muwaqar	152	153	0.0
Qatrana	88	103	0.5
Mufraq	149	165	0.5
200-350 mm			
Shoubak	273	382	3.6
Mazar	284	336	1.7
Busseria	244	260	0.5
Ramtha	273	296	0.8
350-500 mm			
Hawara	326	374	1.6
Irbid	370	450	2.7
Al-Taiyiba	456	513	1.9
Kufr Awan	432	524	3.0
> 500 mm			
Salt	555	1045	3.0
Kitta	478	583	3.5
Kufrinija	582	646	2.1

rainfall reduction should have been occurring for long time, but not to the extent that would justify reclassification of the prevailing climatic zones.

The influence of human factor within the different soil ecosystems in Jordan could not be ignored. Nevertheless, such contribution is considered smaller than the impact of gradual climate change occurring over a long period of time. The contribution of human factor in some areas could be totally ruled out, since degradation within these areas would have required time substantially longer than the period since the beginning of noticeable human activities there. Therefore, the land degradation there should be attributed to long-term gradual climatic changes. Among other strong evidence that substantiates the prevalence of local gradual climate change is the presence of a well developed layer of wind-born calcareous silt sediments over red soils rich in clay (Fig.1).

It is to be noted that a gradual change in climate, as described for Jordan should be a part of the regional climatic pattern. The deposition of the wind sediment flowing into Jordan is, in fact, a part of regional climatic pattern, which could explain what is going on in Jordan. Causes for such regional climatic change have not been yet investigated in-depth at a regional scale. However, local studies had revealed the occurrence of localized climatic changes during the last 5-10,000 years (Taimeh 1984; Begin et al. 1974).

Figure 1. Desertification caused by long-term wind deposition of silt associated with gradual change in climate from very-humid to arid. Top layer shows the wind sediment deposit.

7. Responding to climate changes

Knowledge emerging from better understanding of the impact of climatic changes, or climatic variations, threatening the resources of the dryland regions, can help refine the approaches to adapt to or mitigate such impacts. No single technology is appropriate for all soils, climates, or cropping and farming systems. In this regard, the following issues should be addressed:

- Emerging challenges affecting the production of dry lands, other than land degradation, include greater rainfall variability, increasing drought occurrence and water shortages, abnormal weather conditions (such as floods or frosts), and appearance of new insects and disease.
- There is a need for intensification and diversification of agriculture to meet new demands, ensure market access to marginal populations, change social conditions, and sustain the use of these resources, while creating enough jobs to support livelihood of local inhabitants in these regions. Threatening challenges call for innovative integrated land use management schemes and new income opportunities that will help to increase the resilience of communities in marginal drylands. Development policies and interventions should sufficiently take into account the fragile nature of dryland ecosystems. Sustainable livelihood generation is a key factor in the successful development and enhancement of management approaches. Engaging local communities in the design, planning, and testing of interventions is essential to enhance ownership and make full use of their indigenous knowledge of management practices.
- Cost-effective research is needed to achieve large-scale development of dryland resources, and well being of local population. International cooperation is essential to cope with desertification and land degradation in drylands, as desertification is a cross-border issue. National institutions must be supported with sufficient resources to develop coherent, cohesive and integrated short and long-term technical and policy approaches.
- Knowledge gaps between research and policy-making communities should be bridged.
- Socioeconomic and environmental circumstances must be assessed since the capacity to adapt and mitigate is dependent on these circumstances and the availability of information and technology.
- Neither adaptation nor mitigation alone can avoid all climate change impacts. Adaptation is necessary both in the short and long-term to address impacts resulting from global warming. There are barriers, limits, and costs that are not fully understood. Adaptation and mitigation can complement each other and together they can significantly reduce the risks of climate change.
- There are some problems to be solved before any decision maker could undertake implementation of adaptive measures. These may include:
  - Understanding the specific impacts of climate change at the local level. Uncertainties are involved in scaling down the global climate model output to the high spatial resolutions needed for effective adaptation work at regional and national levels (Nelson 2009).
  - Gap between the seasonal information we currently have and long or short-term impacts of climate change.
  - Communicating the results from modeling scenarios to decision makers, including farmers and policymakers. Scenarios integrating possible socioeconomic (and climate) futures will therefore be central to exploring and communicating adaptation and mitigation approaches.
- Synergies between agriculture-related climate change policies and sustainable development, food security, energy security and improvement of environmental quality need to be identified in order to make mitigation practices attractive and acceptable to farmers, land managers, and policymakers. The greatest opportunities for cost-effective mitigation are through changes in cropland and grazing land management, restoration of organic carbon to cultivated soils, restoration of degraded lands, and agro-forestry (IPCC 2007c).

7.1. Adapting to climate change

Examples of adaptive measures can be as simple as reducing water use by saving and reusing grey water for watering gardens or lawns, or harvesting storm (Rabbinge 2009). Some specific adaptation measures or activities are:

- Integration of disaster management, climate change, environmental management, and poverty reduction.
- Adoption of integrated management of biodiversity outside of formal reserve systems.
- Capacity building for growing alternative crops,

especially those that are drought resistant, or are threatened species with potential future value.
- Allocating land use based on proper selection of crops, which ensure sustainability of land productivity.
- Water storage, ground water recharge, storm protection and flood and erosion control. Development of good practices, such as efficient irrigation technologies, water harvesting, and increased sub-surface storage. Encouraging the development of low-cost technologies for desalinating seawater.
- Integrating community based solutions based on combination of innovative land use, biodiversity, and environmental friendly biotechnology with indigenous knowledge of rural populations.
- Introduction of proper enabling environment.

7.2. Mitigation

The IPCC (IPCC 2001c) concluded that significant reductions in net greenhouse gas emissions are technically feasible due to an extensive array of technologies in the energy supply, energy demand, and waste management sectors, many at little or no cost to society. In addition, afforestation, reforestation, improved forest, cropland and rangeland management, and agro-forestry provide a wide range of opportunities to increase carbon uptake. Also slowing deforestation provides an opportunity to reduce emissions. Nearly 90 % of the mitigation potential (Smith 2009) in agriculture lies in reducing soil carbon dioxide emissions (by restoring cultivated organic soils, for example, or in sequestering carbon dioxide in the soil organic matter of mineral soils). Carbon sequestration in agro-ecosystems holds great promise as a tool for climate change mitigation because it also offers opportunities for synergy with development objectives. Increased C stocks can be achieved through reduced soil respiration losses associated with changes in tillage practices and through changes in land use (Tate et al. 2006; Smith and Conen 2004; Verchot et al. 2000).

Soil carbon sequestration involves adding the maximum amount of carbon possible to the soil. Thus, converting degraded/desertified soils into restored land and adopting resource management practices can increase the soil carbon pool. Examples of soil and crop management technologies that increase soil carbon sequestration include (Rattan 2009):

- No-till farming with residue mulch and cover cropping.
- Integrated nutrient management, which balances nutrient application with judicious use of organic manures and inorganic fertilizers.
- Various crop rotations (including agro-forestry).
- Use of soil amendments (such as zeolites, biochar, or compost); and
- Improved pastures with recommended stocking rates and controlled fire as a rejuvenation method.

Compared to other types of land-use change and to a number of management options, improved grazing, land management, and agro-forestry offer the highest potential for C sequestration in developing countries (about 60% of the grazing lands available for C sequestration are in these countries). Reduced or no tillage, use of nitrification inhibitors and optimum amount and timing of fertilizer application could result in reduced GHG emissions from soils while increasing C stored in soils. Some other management changes that are made mainly for the purposes of adaptation to make agriculture more resilient to climate change also increase carbon sequestration and thus, enhance mitigation. For example, a mix of horticulture crops with optimal crop rotations would promote carbon sequestration and could also improve agro-ecosystem function (Smith 2009).

8. Research needs

Addressing the challenge of climate change requires a broad range of research activities. Mitigation involves the reduction of net emissions from agricultural land, while adaptation involves measures to increase the capability to cope with impacts. Attention will have to be focused on those measures that would reduce GHG emission form biological systems so as to contribute to mitigation.

Climate change places new and more challenging demands on agricultural productivity. It is urgent to pursue crop and livestock research, involving modern tools including biotechnology, to help overcome stresses related to climate change such as heat, drought, and pathogens. Improvements in water productivity is critical, as climate change by making rainfall more variable and changing its spatial distribution will exacerbate the shortage; the need for better water harvesting, storage, and management would therefore increase. Equally important is supporting innovative institutional mechanisms that give agricultural water users incentives to conserve this diminishing resource.

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The Green Morocco Plan in relation to food security and climate change

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Abstract

Morocco is located in one of the most vulnerable regions of the world with respect to climate change. In fact, as an impact of climate change, the land suitable for agricultural production will be reduced to 8 % at the end of the 21st century compared to 12 % at present. The challenge is to produce more food with good quality. This is the objective of the Green Morocco Plan (GMP), the new agricultural development strategy of Morocco. The GMP is based on 6 core ideas: i) A clear conviction that agriculture is a main catalyst for growth to combat poverty, ii) all-inclusive agricultural sector but differentiated strategies depending on target producers, iii) address the underlying problem relating to producers, especially innovative aggregation models that are socially just and adapted to each sub-sector, iv) investment in the agricultural sector with the objective of MAD 10b a year around a targeted Moroccan offer, v) adoption of a pragmatic, transactional approach with 1,000 to 1,500 practical development projects, and vi) no sub-sector is condemned, important is to provide a liberalized market environment to boost growth potential. The reform strategy is built around 2 pillars making agriculture as a major catalyst for economic and social progress with a clear respect of the sustainable development principles. Pillar I deals with the development of a modern agricultural sector based on private sector investment in high productivity/high value added sub-sectors and Pillar 2 concerns the modernisation of production with a social impact using public investment in social initiatives to combat rural poverty. The implementation should take into consideration several transverse problems, especially land tenure, water scarcity, inter-professional organisation, taking advantages of the free trade agreements, doing business and administrative refocus. While the modern agricultural system is based on leading big farmers gets a preference in securing an important part of the domestic consumption and most of the agricultural export, the small farmers' agriculture gets a special attention in the GMP. The GMP offers both an opportunity and a big challenge for the national agricultural research system. Researchers should reduce the productivity- and quality-gaps to ensure sustainability of the agricultural systems in dry areas. The contribution of agricultural science and technology, in climate change context, in meeting the ambitious, but feasible, objectives of the GMP is strategic.

Keywords: climate change; dry areas; Green Morocco Plan; social offer; water scarcity; food security.

1. Moroccan agriculture context

The socio-economic stakes of Moroccan agriculture are huge. From the economic point of view, agriculture is the largest sector in the Moroccan economy. Depending on the growing season, the agricultural sector represents 13 to 20% of total GDP and more than 12 % of total exports (Report 2006). It also has potentially a massive impact on jobs; it employs 40% of the work force and provides 80% of rural jobs. The social impact is high as well as the impact on sustainable development. Agricultural sector plays a major role in the stability of a large number of vulnerable farmers.

The cultivated area of Morocco is dominated by cereals, value-added fruit and vegetable crops for export, and animal farming. Cereals are grown on 68% of agricultural land, mainly under rainfed systems. Their production, which ranges from less than 2 million to more than 10 million metric tons per year, represents a major part in the performance of the agricultural sector and the Moroccan economy as a whole. In average years, the irrigated sector, which represents only 13% of the total arable land, contributes to 45% of agricultural added value, 75% of agricultural exports and 35% of agricultural employment.

Self sufficiency of Morocco food needs by domestic production is 100% for meat, fruits and vegetables, 82% for milk, 62% for cereals, 47% for sugar, 31% for butter and 21% for edible oils. A major constraint is the excessive fragmentation of land holdings. In 1996, the general census of agriculture showed that Morocco had 1.5 million farms, with an average area of 5.8ha each. Landless farmers and smallholders (those cultivating plots of less than 3.0ha), whose main resource is their labour, still represent more than half the total number of farms (54%), holding 12 % of arable land and 18% of irrigated land. Most of these farms, which practice subsistence farming, are very vulnerable to drought and have to have recourse to off-farm income.

Massive shortfalls are also observed in terms of investment and risk-taking; well below international standards. The use of fertilizers and mechanization, as indicators, testify these weaknesses. The use of fertilizers only averages 52kg/ha and the number of tractors 6 per 1000 ha of agricultural area.

There are many constraints: (i) vulnerability of a large number of farmers; (ii) lack of administrative flexibility concerning land issues; (iii) poorly implemented water demand management policy resulting in overexploitation of water resources; (iv) industrial framework sometimes out of step with the fundamental issues relating to deregulation; and (v) lack of modernization of the managerial structure of the concerned governmental body. But, with these constraints there are also huge opportunities: (i) a very strong growth in domestic demand; (ii) huge growth in overall demand for Mediterranean-type products; (iii) recognized comparative advantages in key products; and (iv) European and US markets easily accessible in terms of customs and logistics.

2. Climate change impact on agricultural production in Morocco

IPCC climate projections (unfcc.int/resource/docs/natc/mornc1e.pdf) for Morocco indicate a trend towards an increase in average annual temperature (between 0.6 and 1.1°C by 2020), a decrease in average annual rainfall (by about 4% in 2020 compared to 2000 levels), an increase in the frequency and intensity of frontal and convective thunderstorms in the north and the west of the Atlas Mountains, an increase in the frequency and intensity of droughts in the south and the east of the country, a disturbance in seasonal rainfall (winter rains concentrated during a short period of time), and a reduction in the period of snow cover.

While global warming and climate changes would be affecting agricultural production, the availability of one important resource for coping with hotter and drier conditions, irrigation water, may be adversely affected. The first quantitative estimate of possible climate change impacts on water resources in 2020 points to an average and general decrease in water resources (in the order of 10 to 15 % - these figures being of the same magnitude as those advanced for two neighboring countries, Algeria and Spain). Morocco's water needs in 2020 are estimated at 16.2 billion m³, taking into account the expected increase in temperature. However, the mobilization of the 17 billion m³ that would be theoretically available in 2020 (taking into consideration climate change effects), would require great investments (dam construction, drilling of deep wells).

IPCC climate change projections were downscaled to the level of 6 agro-ecological zones in Morocco, and agricultural yield projections were simulated for 50 rainfed and irrigated crops, for 2 greenhouse gas emission scenarios A2 and B2 and for 4 time horizons: 2000 (current period, covering 1979 to 2006), 2030 (from 2011 to 2040), 2050 (from 2041 to 2070) and 2080 (from 2071 to 2099). This study statistically down scaled the climate projections established by the IPCC, from grid-boxes of 250km x 250km at the global level to a small enough size (about one hundred square km) compatible with the scale of the principal agro-ecological zones of Morocco, corresponding to the grid-boxes of 10km x10km.

Due to climate change, increasing aridity and some extreme events (e.g. floods) are predicted for Morocco as shown in Figure 1. Morocco will experience gradually increasing aridity because of reduced rainfall and higher temperatures. Increased aridity will have negative effects on agricultural yields, especially from 2030 onwards and, rainfed crops (non-irrigated) will be particularly affected by climate change. However, it is uncertain whether increased water demand for irrigated crops can be met under the drier climate predicted for the climate change scenarios. Technological advancements (agricultural yield improvements in arid and semi-arid conditions), improved irrigation water management (at the level of agricultural

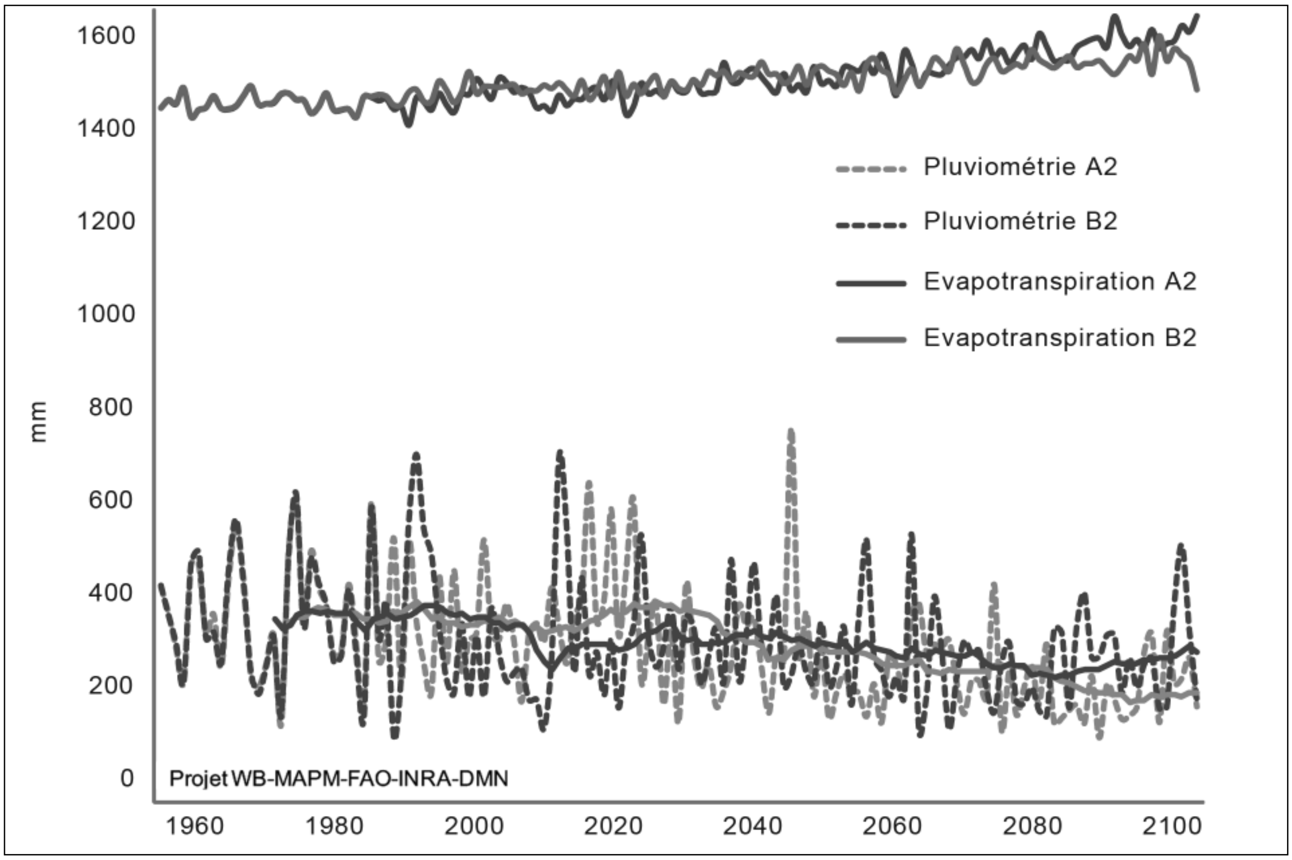

Figure 1. Climate change prediction in Morocco.

plot, catchment area and the region), and land use according to its suitability are significant keys for adapting to climate change; adaptation to climate change and variability can also be facilitated through effective planning and implementation of strategies at the political level (http://ext-ftp.fao.org/SD/Reserved/Agromet/WB_FAO_morocco_CC_yield_impact/report/).

3. The Green Morocco Plan

The new Green Morocco Plan (*Plan Maroc Vert* 2008) is intended to implement an agricultural policy that will bring about: (i) the competitive upgrading of the agricultural sector in the perspective of modernization and integration into the world market, and the creation of wealth for the whole value chains; (ii) the inclusion of the whole sector in all its economical, sociological, environmental and territorial components into consideration, with priority being given to sustainable human development objectives; (iii) the greater optimization and sustainable management of natural resources; and (iv) clear defining of support policies needed for sustainable growth.

The Green Morocco Plan (GMP) is based on six core ideas:

i. A clear conviction that agriculture is a main catalyst for growth to combat poverty,
ii. An all-inclusive agricultural sector but differentiated strategies depending on target producers,
iii. Address the underlying problem relating to producers, especially, innovative aggregation models, which are socially just and adapted to each sub-sector,
iv. Investment in the agricultural sector around a targeted " Morocco offer,"
v. Adoption of a pragmatic, transactional approach, with 1000 to 1500 practical development projects, and
vi. No sub-sector to be neglected and the provision of a liberalized market environment to boost growth potential.

This new strategic context of the GMP is a reform strategy built around two pillars:

- **Pillar I –** Aggressively develop a high value-added/high productivity agricultural sector.
- **Pillar II –** Modernisation with a social impact – investment in social initiatives to combat rural poverty.

In fact, the strategy rests on the two essential pillars, which make it possible to act on both modern farms (Pillar I) and small farms (Pillar II). Pillar I has the objective of developing an efficient, market-oriented agriculture through private investment for the implementation of development plans for high added-value and highly productive commodity chains. Pillar II has the objective of developing an approach that focuses on reducing poverty by significantly increasing the agricultural income of the most vulnerable farmers, particularly in mountainous and unfavourable rain-fed agricultural zones and oasis production systems, through social investments implementing aggregation projects for marginal areas. The Pillar II projects are intended to foster a shift to more appropriate and profitable commodity chains, through intensification and enhancement measures in order to give the social fabric greater solidarity and foster community aggregation in rural areas. The GMP is underpinned by a series of reforms of: (i) the sectoral framework (land tenure, water policy, taxation, etc.); (ii) the institutional re-organization of the Ministry of Agriculture itself; and (iii) coordination with other public organizations with regard to rural development.

While the modern agricultural system in the GMP is based on providing big farmers preference in securing an important part of domestic consumption and most of the agricultural export through highly ambitious plans for sub-sectors, enormous opportunities for fresh and transformed products, and strong guarantees for aggregation models, the GMP gives small farmers a special attention. That is why the "Moroccan Social Offer" is a unique value proposal that aims to reduce rural poverty. This proposal has four dimensions:

- Diverse portfolio of pre-packaged practical projects:
  a. Projects aimed at **reconversion** to higher income farming activities;
  b. Projects aimed at **intensification** and supervision of existing farms;
  c. Projects aimed at **diversification** of both crops and sources of farming income.
- Social projects having a potentially huge impact:
  d. Target zones of rural poverty as a priority;
  e. Several thousand farms affected by this project;
  f. Increase by 2 to 5 times the farming income of targeted farms.
- Accessibility to leading social institutions at ground level:
  g. A solid network of trade associations and cooperatives;
  h. Massive commitment of the financial sector to the rural population;
  i. Involvement of leading international social institutions.
- Establish genuine long-term partnerships:
  j. Long-term commitment with projects spanning several years;
  k. Strong involvement and joint-investment by the Moroccan government in projects;
  l. Strong execution capacity and control by the Moroccan administration.

At the heart of Pillar 2 lies the regional development strategy aimed at carrying out reconversion and/or aggregation projects as a way to combat poverty at its source and to ensure food security.

Strategy of providing proactive support to farmers: Complementary strategy of providing proactive support to producers to cover all farms as a way to combat poverty includes adoption of a set of new measures with a value proposition adapted to social investors:

i. Social aggregation projects around operators or associations possessing extensive regional coverage and enhancement techniques (logistics, supervision, transformation),
ii. Integrated reconversion projects taking into account realities/social risks along the lines of the reconversion model adopted as part of the MCA (Millennium Challenge Account), and
iii. Supervision overhauled and re-launched around new structures and new contract-programmes involving regions, sub-sectors and farmers – use of public-private sector partnerships as the best way of providing support services

Integrating these measures in an integrated development strategy: The integration of these measures in an integrated development strategy is based on 3 elements:

i. Basic public services
ii. Diversification of revenues
iii. Social Policy

Major changes in institutional, managerial and financial resources

There are three pillars for the reorientation of the government, which is compatible with the new business environment resulting from the arrival of well-structured private-sector players, with the focus on regulatory and operational functions increasingly to be transferred to the private sector:

i. Increasing the use of Public-Private Partnership for operational functions, especially:

Irrigation management

a. The " large scale" irrigation projects given over to delegated management (via concessions);
b. Service providers chosen on the basis of competition (tenders);
c. Economical water pricing policy to be implemented progressively.

Supervisory-related services

a. Progressively outsourced to the private sector;
b. Creation of a job profile known as Private Agricultural Advisor (e.g. certification, help with setting up, etc.).

ii. Creation of new entities/skills in the context of implementing the strategy:

a. Agricultural Development Agency (ADA) dedicated to implementing the strategy and possessing the necessary human and financial resources;

b. National Office of Sanitary Health of Products (ONSSA *'Office National de la Santé Sanitaire des Aliments'*), an authority independent of the Ministry of Agriculture, responsible for regulatory matters, quality control and health and safety standards.

iii. Creation and promotion of a trade association (GIPA) around 5 key areas:

a. Agrotech and Research and Development (R&D);
b. Access to production inputs and mechanization;
c. Exports, logistics and packaging;
d. Human resources development and training;
e. Branding and quality management.

These pillars are set along with the overhaul of the Ministry's internal management processes through rationalization of management processes and procurement of highly qualified human resources. Equally, additional financial and budgetary resources are needed.

Impact of social projects at national level

The potential impact of social projects of reconversion, intensification/quality improvement, and diversification/niche projects can be summarized as follows:

- *Target :* ~500,000-600,000 farms (~40% of Morocco's farms), ~3 million rural persons
- *Surface area:* 800,000-900,000 ha (~10% of agricultural arable land)
- Investment: MAD 16-18bn over 10 years (US$ 1= 8.42 Moroccan Dirhams, MAD)
  - Upstream: MAD 11-12bn
  - Downstream: MAD 5-6bn
- *Objective:* increase farming income by 2 to 10 folds for targeted farms.

4. Research and development contribution to upgrade agricultural sector under erratic climate events

For nearly one century, the National Institute of Agricultural Research (INRA) has been evolving in terms of organization and research strategy. Thanks to its research achievements, INRA is among the national institutions that have contributed significantly to the modernization of the Moroccan agriculture through basic knowledge and technology development.

Working to get client oriented research achievements and to consolidate regional anchorage is a strategic priority of the Institute. The will of INRA is strongly expressed by the involvement of its partners, stakeholders and regional operators in orienting, monitoring and using research results. This is also the role of the 'Regional Council for Agricultural Research' which is an important forum for holding debates and information exchange.

In addition, communication and technology transfer is a key element of INRA vision. Its information and communication division is sparing no effort to promote internal and external communications and to improve its information management system. INRA has now a solid basis to achieve defined objectives and thereby support the

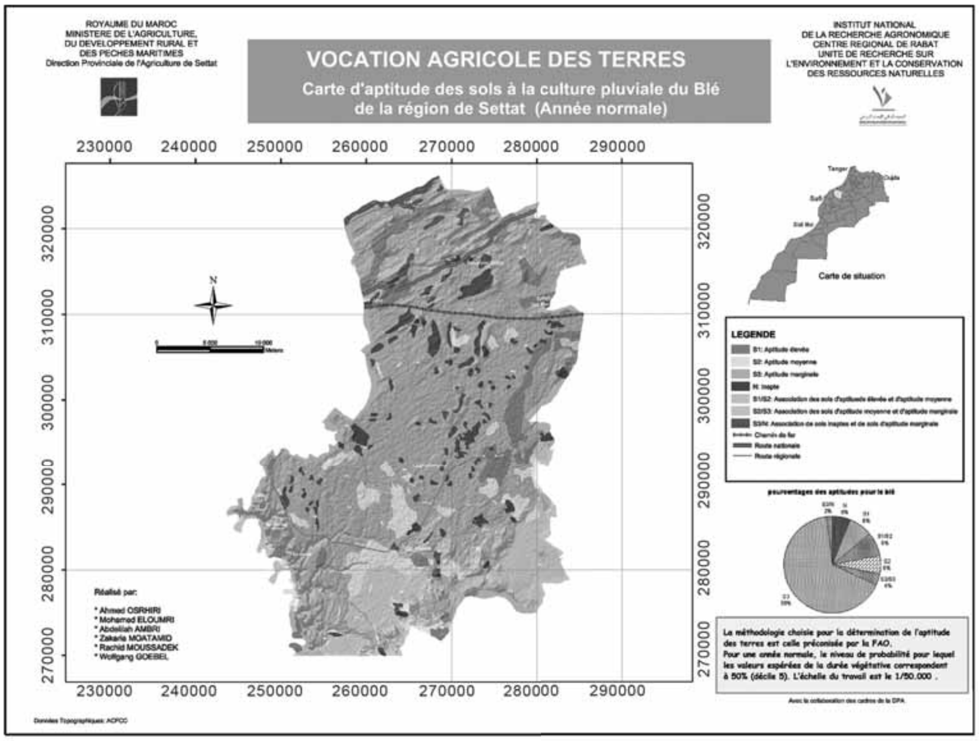

Figure 2. Example of land suitability map for rainfed wheat in Settat region for an average year.

new agricultural development strategy, the 'Green Morocco Plan'.

At the same time, opening up and partnership dimension is also a field to further strengthen collaboration at the national and international levels for better use of research results and for raising R&D to a level in harmony with public and private operators' needs.

Considerable amount of research to 'research for development' work has been and is still being conducted by NARs in Morocco to develop proven soil, water, and crop management practices combined with improved cultivars to enhance water use efficiency of cropping systems, thereby permitting sustainable increases in productivity and ensuring food security. The achievements testify greatly the pertinent role of INRA in upgrading the agricultural sector in erratic climate events (Badraoui et al. 2009).

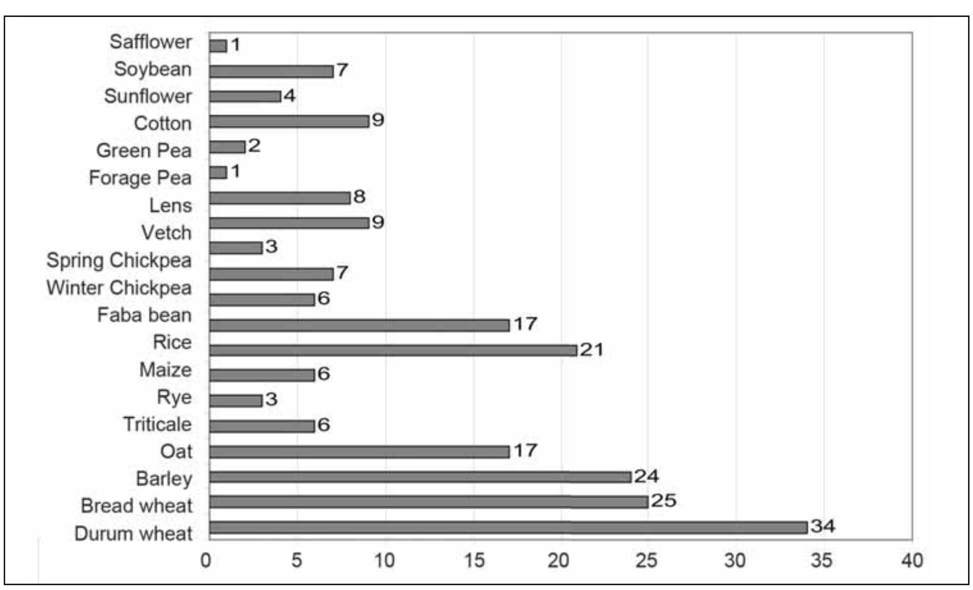

Figure 3. Number of released varieties of different crops.

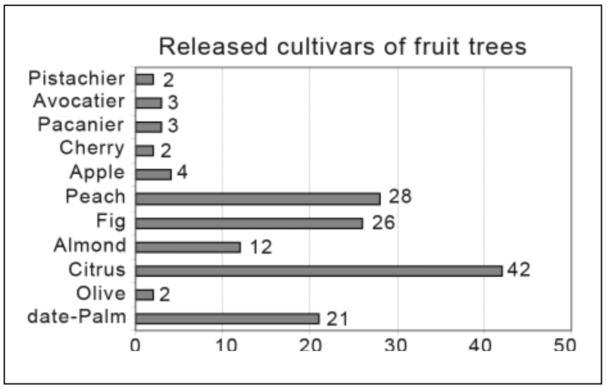

Fig. 4. Number of released cultivars of fruit trees.

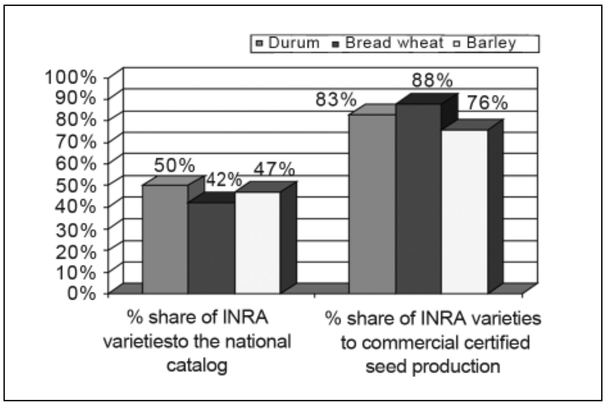

Fig. 5. Percentage of share of INRA varieties in the official cereal Catalog of Morocco and percentage of share of INRA varieties in the commercial certified seeds for cereals in Morocco.

Land suitability maps: Maps of 5.5 million hectares of rainfed agricultural lands have been elaborated as decision making tool for optimal management of natural resources (water and soil) based on climatic, soil and crop growth and development needs (Fig. 2). These maps serve also as basis of identification of production basins, elaboration of soil fertility maps, and orientation of government policy in terms of support or subsidies and planning of land use.

Crop improvement: Plant breeding program for major crops and fruit trees at INRA has led to the development of adapted cultivars to the prevalent Mediterranean conditions (Fig. 3 and 4). The outcome, both rich and varied, is characterised by registration in the Moroccan official catalogue of 216 varieties of cereals adapted to diverse Moroccan agro-ecological zones, Besides, the percentage of share of INRA varieties in the Official Catalogue and in the commercial certified seeds is shown in Figure 5.

These programs had a major impact on agricultural production improvement. For instance, technological progress, recorded during the last 25 years nationwide based on agricultural statistics, averaged 0.2 quintals per hectare per year for wheat. This progress is mainly due to INRA efforts in upgrading cereal production in term of variety improvement, adapted to climate conditions of the country.

In the olive improvement program, 8 millions olive trees of the INRA's new varieties Menara and Haouzia were distributed to farmers. Another example with major impact is date palm variety 'Najda'. This variety constitutes a turning point toward Moroccan date palm rehabilitation. Its main features are the agronomic traits: time of pollination in March, very long floral receptivity after spathe opening, long fruit season, average temperature requirement for the maturity of the fruit, high productivity, good presentation and appearance of dates, good ability for fruit conservation and resistance to the devastating disease *bayoud*. There is also development of new citrus varieties productive and adapted to market requirements: three new triploid hybrids of good quality sperms are currently being tested. These new varieties are currently being processed under plant protection act. They will be released once protected. A large program of associated varieties / rootstock selection is being performed.

Biodiversity conservation: Although, Morocco falls within arid and semi-arid environments, it has a wide range of geo-morphological features and sub-climatic zones which have created unique diverse ecosystems and extremely rich communities of flora. The flora of Morocco consists of more than 7000 plant species with more than 20% of endemism. It is thus characterized by its tremendous diversity at all levels of biodiversity of ecosystems, species and within-species diversity that include landraces and wild relatives of cultivated species. This diversity, however, has been undergoing genetic erosion due to a number of factors (e.g. urbanization, overgrazing, and desertification) and this has intensified over the last years as a result of consecutive years of drought and desertification. A number of species described in the past are either highly threatened or extinct. Others are rare and confined to inaccessible mountains areas with sharp slope. As a result of the boom in local use and export trade of many species from the wild, about 75 of the rare species are at the edge of extinction in Morocco. This loss of diversity is detrimental as people rely on it for their income and well-being. INRA has developed a gene bank with a medium and long-term storage facility. It can store more than 65,000 accessions. More than 25000 accessions of 256 different species are held in the cold store (Fig.6).

Supplemental irrigation: Substantial increases in crop yield in response to the application of relatively small amount of supplemental irrigation (SI) in both low and high rainfall areas. The need for SI water would vary from 60 to 180mm depending on rainfall. The WUE increase due to SI varied from 30% to 96% in high and low rainfall season, respectively (Boutfirass 1997; Boutfirass et al. 1999).

Agronomic management: By designing optimum planting date through shifting cropping seasons to cooler, more humid periods of the year to improve the transpiration efficiency, as is the case of winter chickpea and other crops (Kamal and Dahan 1994); sowing to avoid probable stress periods during anthesis of the crop, or manipulating the ratio of early-season to late-season water use crop yields have increased (Boutfirass et al. 2005). Similarly, optimum seed rate and plant geometry to fully exploit the available soil water for the complete season have been investigated. Past and on-going research on soil fertility management has demonstrated a proven potential to make a sustainable and economic contribution to increased productivity (Elmjahed 1993; Elmjahed et al. 1998).

Moreover, strategies involving tillage, herbicides, and crop rotations to control weeds and reduce competition for water have been developed. Within variable agro-ecological settings, comparisons of different crop rotations with regard to tillage, fertilizers application, nutrients availability, weed management strategy, water storage, WUE and yields were investigated. Their role in diversifying the cropping systems, in optimizing water and nutrient use, and in managing population levels of disease pathogens and weeds have been documented (Bouzza 1990; Elmjahed 1993; Elmjahed et al. 1998; Kacemi et al. 1994; Kamal and Dahan 1994; Masood et al. 2000).

Conservation tillage: In Morocco, arable land is undergoing degradation at alarming rates, either due to inappropriate soil and vegetation use or due to weather impacts (drought and erosion).

The results from research (Bouzza 1990) and on-farm trials in the 1990s recognized that no-tillage system could halt or reverse decreased production and land degradation, reduce costs, labor and energy use, and improve production. Figure 7 shows mean grain yield over 9 years period on farm pilot site of no-till versus conventional tillage in

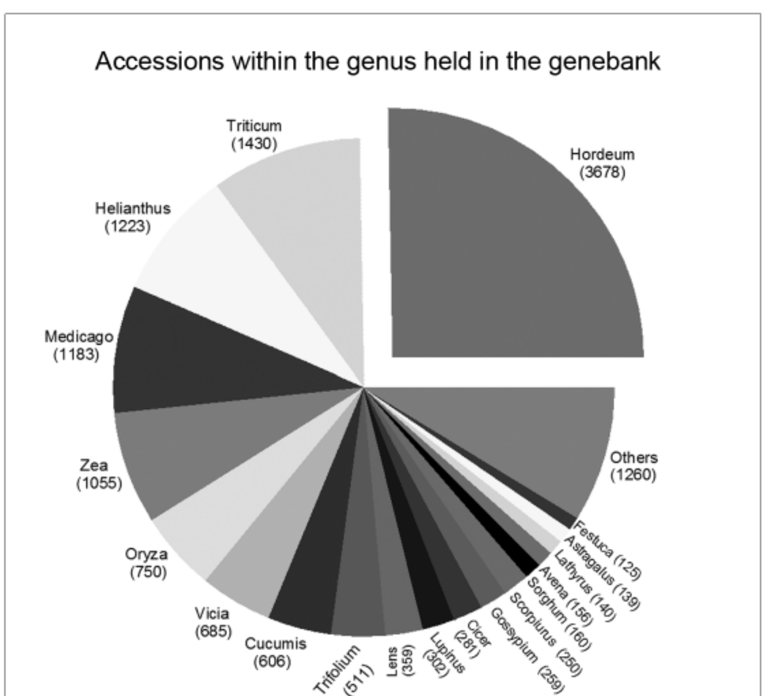

Figure 6. Most occurring genera and the number of accessions held in the gene bank of INRA.

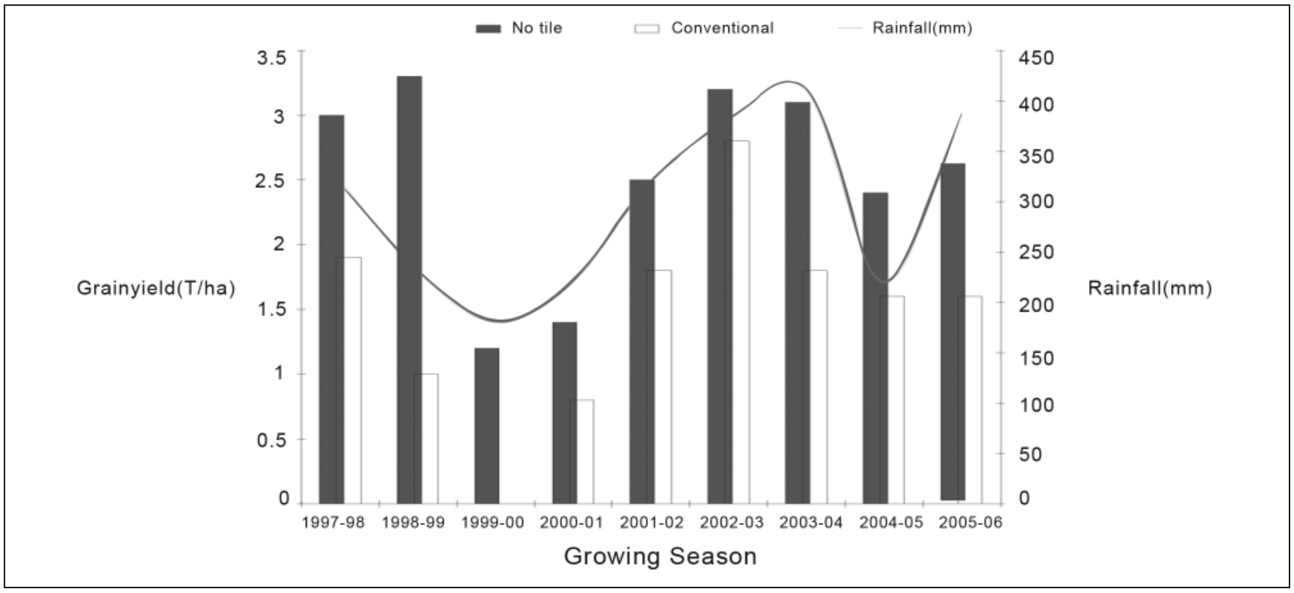

Figure 7. Mean grain yield over 9 years period on farm pilot site of no till versus conventional tillage in a semi-arid area

a semi-arid area where proven principles of soil and water management have been tested (Mrabet, 2002, 2008). Long term trials, over a 9-year period, show the superiority of no-till system compared to conventional system; grain yield has been increased by 30 to 40 % in average, organic matter by 3 to 14%, WUE by 60% and energy consumption has been reduced by 70%.

Small ruminants: Five production systems for sheep and three for goats and the performance of sheep (‘Boujaâd’, ‘D’man’, ‘Sardi’) and goats (population local du Nord, race ‘Draâ’) have been characterized. Knowledge and recommendations of specific feeding integrating local products have been diffused. Breeding for new races is underway.

Major contributions can be anticipated from improved soil, crop, and cropping system management. The challenge is to coordinate land and water management with the use of water and nutrient-efficient cultivars in sustainable cropping system to increase biological and economic outputs while taking into account the conservation of natural resource base.

5. Green Morocco Plan - opportunities and challenges

GMP considers a number of projects with quantified objectives and improved governance. It has a portfolio of 1,506 projects, 961 for Pillar I and 545 concerning Pillar II, aiming at the improvement of productivity and quality, and also the valorization products in all potential sub sectors in the 16 regions of Morocco. The regionalization of the GMP through 16 regional agricultural programs constitutes the framework of integration and roadmap of agricultural development. GMP offers a new strategy of agricultural and rural development using improved governance in its implementation, based on decentralization, partnership, contracting, and evaluation to achieve the quantified objectives.

A central objective of the GMP is the reorientation, diversification, intensification and enhancement of agricultural production. The implementation of such objective is an innovation that is backed up by a public policy of targeted support. INRA, by identifying the needs of farmers and all stakeholders, has directed its scientific research priorities towards the commodity chains for both small-scale rainfed agriculture in vulnerable zones (Pillar 1) and high value added/high productivity agricultural sector (Pillar 2).

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Addressing climate change and food security concerns in the Asia-Pacific region

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Abstract

Agriculture remains important for economic growth, livelihood and sustenance for majority of the people in the Asia-Pacific region forming about 57% and 73% of the world's total and agricultural population, respectively. The land availability per person is only about one fifth of that in the rest of the world. Research in the agricultural sector led to remarkable achievements in the past to attain food security and reduction in poverty. Agricultural population is dominated by small farm holders, pastoralists, tribal people, fishermen and agricultural laborers. However, about 63% (640 million) of the world's hungry and malnourished, 50% (over 660 million) of the world's extreme poor (living on less than US$ 1/day), and 70% of the world's undernourished children and women live in the Asia-Pacific region. Over the last two years, the number of hungry in the region has increased by about 11%. The Millennium Development Goals, especially to reduce hunger and poverty to half by 2015, are no longer closer to be achieved despite all commitments and on-going efforts. The region is facing stagnation or slow down of productivity growth rates, soaring food prices, increasing energy costs, diversion of area for biofuel production, consequences of the climate change and economic shocks. The problems of the numerous and geographically dispersed smallholders and other resource poor communities, who form the bulk of agricultural population, persist: low yields, low returns from farming, and inadequate access to resources and markets. Natural resources, particularly land and water, are becoming scarcer and degraded. In addition, impact of climate change on food security is now a real concern. Addressing these complex challenges, with opportunities to harness new innovations, will now require out-of the-box solutions (technology, institutions, policies, and higher investment). Previous analyses have unequivocally shown that investments in agricultural research had high rates of return both in terms of growth and poverty reduction in the region. Asia-Pacific Association of Agricultural Research Institutions (APAARI), being a neutral forum to foster partnership among major research institutions (NARS, CG Centers, ARIs and other regional fora) in the region, has recently revisited agricultural research priorities to address specific concerns of climate change and food security by holding two expert consultations involving key stakeholders. As a result, "Tsukuba Declaration" on climate change and "Bangkok Declaration" on AR4D have clearly drawn a future road map for the reorientation of agricultural research for inclusive growth and development, as well as to ensure large scale impact on poverty and hunger.

Keywords: agriculture research for development (AR4D), Asia-Pacific region, climate change, poverty alleviation, investment in research.

Introduction

The impressive economic growth and globalization of agricultural input-output markets during the past four decades have helped the Asia-pacific countries to synchronise the demand and supply of food in the region. However, the challenges ahead are to meet demand of quality food for ever-increasing populations, degradation of land and other natural resources and on the top of it, the changing global climates. The compounded challenges of global climate change are likely to impact crop and livestock production, hydrologic balances, input supplies and other components of agricultural systems, making agricultural production much more variable than at present. Furthermore, human activities have contributed substantially to over-exploitation of natural resources, substantially increasing the concentration of greenhouse gases (GHGs), and average temperature of the earth's surface.

Emissions of green house gases (GHGs), like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), has increased by 36%, 17% and 151% during the last century (Preston et al. 2006). Of this increase, industrialization contributed 67 % and remaining 33 % by the land-use changes. Agriculture, consisting of cropland, pasture, and livestock production, presently contributes 13% of total anthropogenic greenhouse gas emissions. The increase in GHGs in the atmosphere is now recognized to contribute to climate change (IPCC 2001). Therefore, food security is inextricably linked with climate change and population pressures (Brown 2008; FAO 2006, 2007). Recent studies indicated that crop net revenues would fall by as much as 90% by 2100, with small-scale farms being the most affected (Benhin 2006).

The affluency of food demand and supply needs prudent management of the global and regional agricultural resources (arable land, water, energy, and fertilizer) through technical improvements in these changing climatic scenarios.

Asia-Pacific region accounts for 57% of the world's total and 73% of the agricultural population, with 1/3rd of global land. It is estimated that by 2020, food grain requirement in Asia would be 30-50% more than the current demand and will have to be produced from same or even less land; that too with inferior quality of other natural resources. Hence, the world food situation will be strongly dominated by the changes that would occur in Asia because of its huge population, changing diet pattern and associated increase in demand for food, feed, fibre, fuel etc. Additionally, increased energy needs of Asian countries to sustain rapid economic growth in the years to come will have profound impacts on global climate change and energy security for the region and the world (USAID 2007; IEA 2006; Saha 2006).

Above facts draw global concerns and urgency to address the options by which threats to Asian agriculture due to climate change can be met successfully in the near future. On the positive side, the agriculture sector also provides significant potential for the greenhouse gas mitigation and adaptation to climate change effects.

This, however, would demand reorientation of agricultural research that would comprehensively address all urgent concerns of climatic change through well defined adaptation and mitigation strategies which could help maximizing food production, minimizing environmental degradation and attain socio-economic development.

Impact of climate change on agriculture

Climate change is projected to impinge on sustainable development of most developing countries of Asia as it compounds the pressures on natural resources and the environment associated with rapid urbanization, industrialization, and economic development. The impact of climate change on agriculture is now real and without adequate adaptation and mitigation strategies to climate change, food insecurity and loss of livelihood are likely to be exacerbated in Asia.

In this regard, the fourth assessment report of the Inter-Governmental Panel on Climate Change (IPCC), released in 2007, has clearly revealed that increases in the emission of green house gases (GHGs) have resulted in warming of the climate system by 0.74°C between 1906 and 2005 and further projected to increase 2 to 4.5°C by the end of this century. The irrigated lands, representing a mere 18% of global agricultural land producing 1 billion tonnes of grain annually (about half the world's total supply), are likely to decrease or adversely affected by global climate change (FAO 2003). Extreme events including floods, droughts, forest fires, and tropical cyclones have already increased in temperate and tropical Asia in the last few decades. IPCC has predicted that sea-level rise and an increase in the intensity of tropical cyclones is expected to displace tens of millions of people in the low-lying coastal areas of Asia with expectation of around 17% land getting inundated in Bangladesh alone. On the contrary, the increased intensity of rainfall and contraction of monsoon period would increase flood risks in temperate and tropical Asia.

Asia-Pacific Association of Agricultural Research Institutions (APAARI), which has been instrumental in promoting regional cooperation for agricultural research in the Asia-Pacific region has been organizing series of expert consultations for debating on emerging issues vis-à-vis agricultural research and development (ARD) concerns in the

Asia-Pacific region. In this endeavor, 'food crisis' and 'climate change' were identified as major themes during the expert consultation on 'Research Need Assessment' organized by APAARI during 2006. Accordingly, the issue of climate change and its imperatives for agricultural research in the Asia-Pacific region was deliberated in an International Symposium jointly organized by APAARI and JIRCAS. Participants including NARS, CGIAR, IARCs, GFAR, ACIAR, JIRCAS, ARIs, universities and regional fora from 30 countries have came out with agricultural research priorities for adapting agriculture to climate change in the form of "Tsukuba declaration on adapting agriculture to climate change" (APAARI 2009).

Tsukuba declaration on adapting agriculture to climate change

- The Asia-Pacific region sustains almost half of the global people, with high rates of population growth and poverty. Agriculture continues to play a critical role in terms of employment and livelihood security in all countries of the region. The IPCC has considered the developing countries of the Asia-Pacific region, especially the mega-deltas of Asia, as very vulnerable to climate change.
- Attainment of Millennium Development Goals (MDGs), particularly alleviating poverty, assuring food security and environmental sustainability against the background of declining natural resources, together with a changing climate scenario, presents a major challenge to most of the countries in the Asia-Pacific region during the 21st century.
- Water is a key constraint in the region for attaining food production targets and will remain so in future as well. Steps are, therefore, needed by all the stakeholders to prioritize enhancing water use efficiency and water storage.
- It was fully recognized that increasing food production locally will be the best option to reduce poor people's vulnerability to climate change variations and a concerted effort, backed by policy makers at the national level would be the key to enhance food security as well as ensuring agricultural sustainability.
- New genotypes tolerant to multiple stresses: drought, floods, heat, salinity, pests and diseases, will help further increase food production. This would require substantial breeding and biotechnology (including genetically modified varieties) related efforts based on collection, characterization, conservation and utilization of new genetic resources that have not been studied and used. CGIAR Centers, Advance Research Institutes (ARIs) and the National Agricultural Research Systems (NARS) of the region have a major role to play in this context. This will require substantial support in terms of institutional infrastructure, human resource capacity and the required political will to take up associated agricultural reforms. We, therefore, fervently call upon the national policy makers, overseas development agencies (ODA), other donor communities as well as the Private Sector to increase their funding support for agricultural research for development in the Asia-Pacific region.
- It was also recognized that a reliable and timely early warning system of impending climatic risks could help determination of the potential food insecure areas and communities. Such a system could be based on using modern tools of information and space technologies and is especially critical for monitoring cyclones, floods, drought and the movements of insects and pathogens. Advanced research institutions, such as JIRCAS, could take the lead in establishing an 'Advance Center for Agricultural Research and Information on Global Climate Change' for serving the Asia-Pacific region.
- The increasing probability of floods and droughts and other climatic uncertainties may seriously increase the vulnerability of resource-poor farmers of the Asia-Pacific region to global climate change. Policies and institutions are needed that assist in containing the risk and to provide protection against natural calamities, especially for the small farmers. Weather-crop/livestock insurance, coupled with standardized weather data collection, can greatly help in providing alternative options for adapting agriculture to increased climatic risks.
- Governments of the region should collaborate on priorities to secure effective adaptation and mitigation strategies and their effective implementation through creation of a regional fund for improving climatic services and for effective implementation of weather related risk management programs. Active participation of young professionals is also called for.
- It was recognized that there are several possible approaches to enhance carbon sequestration in the soils of the Asia-Pacific region such as

greater adoption of scientific soil and crop management practices, improving degraded lands, enhanced fertilizer use efficiency, and large scale adoption of conservation agriculture. To be effective, these would require simultaneously improved use of inputs such as fertilizers, crop residues, labor and time. This soil carbon sequestration has the added potential advantage of enhancing food security at the national/regional level. We do urge the global community to ensure appropriate pricing of soil carbon and related ecosystem/environmental services in order to motivate the small farmers to adopt new management practices that are linked to proper incentives and rewards.
- APAARI has been instrumental in stimulating regional cooperation for agricultural research in the Asia-Pacific region. Global climate change and its implications for agriculture underline the need for such an organization to become even more active at this juncture. APAARI, in collaboration with its stakeholders, especially CGIAR Centers, ARIs, GFAR and other regional fora, should continue facilitating regional collaboration in a Consortium mode and take advantage of new initiatives such as Challenge Program on Climate Change for building required capability to adapt and mitigate the effects of climate change and ensure future sustainability of all concerned in the region.

Research priorities for coping with global climate change

Coping with global climate change is a must and for that there are two strategies (i) Adaptation through learning to live with the new environment (e.g., time of planting, changing varieties, new cropping systems, etc.) and (ii) Mitigation through offsetting the causative factors such as reducing the net emission of greenhouse gases.

Adaptation strategies: The potential strategies and actions for adaptation to climate change effects could be as follows:

1. New genotypes
- Intensify search for genes for stress tolerance across plant and animal kingdom.
- Intensify research efforts on marker aided selection and transgenic development.
- Develop genotypes for biotic (diseases, insects etc.) and abiotic (drought, flood, heat, cold, salinity) stress management either by traditional plant breeding, or genetic modification.
- Attempt transforming C3 plants to C4 plants.

2. New land use systems
- Shift of cropping zones.
- Critical appraisal of agronomic strategies and evolving new agronomy for climate change scenarios.
- Exploring opportunities for maintenance / restoration/ enhancement of soil properties.
- Use of multi-purpose adapted livestock species and breeds.

3. Value-added weather management services
- Developing spatially differentiated operational contingency plans for temperature and rainfall related risks, including supply management through market and non-market interventions in the event of adverse supply changes.
- Enhancing research on applications of short, medium and long range weather forecasts for reducing production risks.
- Developing knowledge based decision support system for translating weather information into operational management practices.
- Developing pests and disease forecasting system covering range of parameters for contingency planning and effective disease management.

4. Integrated study of 'climate change triangle' and 'disease triangle', especially in relation to viruses and their vectors.

5. Documentation of indigenous traditional knowledge (ITK) and exploring opportunities for its utilization.

6. Reforming global food system.

Mitigation strategies: The basic strategies for mitigating climate change effects are reducing and sequestering emissions. However, before jumping the bandwagon of mitigation strategies, the following points should be considered for effective implementation of mitigation strategies.

- Improve inventories of emission of greenhouse gases using state of art emission equipments coupled with simulation models, and GIS for up-scaling.

- Evaluate carbon sequestration potential of different land use systems including opportunities offered by conservation agriculture and agro-forestry.
- Critically evaluate the mitigation potential of biofuels; enhance this by their genetic improvement and use of engineered microbes.
- Identify cost-effective opportunities for reducing methane generation and emission in ruminants by modification of diet, and in rice paddies by water and nutrient management. Renew focus on nitrogen fertilizer use efficiency with added dimension of nitrous oxides mitigation.
- Assess biophysical and socio-economic implications of mitigation of proposed GHG mitigating interventions before developing policy for their implementation.

1. Reducing emissions: The strategies for reducing emissions include:

- Avoiding deforestation,
- Minimizing soil erosion risks,
- Eliminating biomass burning and incidence of wild fires,
- Improving input use efficiency (e.g., fertilizers, energy, water, pesticides), and
- Conservation Agriculture.

2. Sequestering emissions: The stored soil carbon is vulnerable to loss through both land management change and climate change. There are numerous agricultural sources of GHG emissions (Duxbury 1994) with hidden C costs of tillage, fertilizer, pesticide use and irrigation. In general, net C sequestration must take into account these costs. The important strategies of soil C sequestration include restoration of degraded soils, and adoption of improved management practices (IMPs) of agricultural and forestry soils. For example in India, the potential of soil C sequestration is estimated at 39 to 49 (44 ± 5) Tg C/y of which 7 to 10 Tg C/y for restoration of degraded soils and ecosystems, 5 to 7 Tg C/y for erosion control, 6 to 7 Tg C/y for adoption of IMPs on agricultural soils, and 22 to 26 Tg C/y for secondary carbonates (Lal 2004). Therefore, agricultural practices collectively can make a significant contribution at low cost to increasing soil carbon sinks and reducing GHG emissions.

A large proportion of the mitigation potential of agriculture (excluding bio-energy) arises from soil carbon sequestration, which has strong synergies with sustainable agriculture and generally reduces vulnerability to climate change. A considerable mitigation potential through sequestration is available from reductions in methane and nitrous oxide emissions in some agricultural systems. However, there is no universally applicable list of mitigation practices and the mitigation through sequestration practices need to be evaluated for individual agricultural systems and settings (e.g. conservation tillage). The biomass from agricultural residues and dedicated energy crops can be an important bio-energy feedstock, but its contribution to climate mitigation to 2030 depends on demand for bio-energy from transport and energy supply, on water availability, and on requirements of land for food and fibre production. Hence, widespread use of agricultural land for biomass production for energy may compete with other land uses and can have positive and negative environmental impacts and implications for food security.

Global Conference on Agricultural Research for Development (GCARD)

Recent Global Conference on Agricultural Research for Development (GCARD) jointly organized by Global Forum for Agriculture Research (GFAR) and the CGIAR Science Council alliance during March 28-31, 2010 in Montpellier, France for developing CGIAR's Strategy and Results Framework (SRF) is a new initiative in the direction to address the major issues - food security, poverty and environmental sustainability. A commonly agreed message arising from the discussions was that the work of the international research sector needs to be embedded in the wider frame of partnership and action to achieve developmental impact by:

1. Creating and accelerating sustainable increase in the productivity and production of healthy food by and for the poor (Food for People),
2. Conserving and enhancing a sustainable use of natural resources and biodiversity to improve the livelihoods of the poor in response to climate change and other factors (Environment for People),
3. Promoting policy and institutional change that will stimulate agricultural growth and equity to benefit the poor, especially rural women and other disadvantaged groups (Policy for People).

The designated key objectives of the SRF are to define the system level results; to identify indicators or impact pathways for measuring the contributions towards these system-level results; and, of utmost importance, to channel CGIAR's research energies, activities and resources so that they produce outputs that lead to impacts that contribute directly to these system-level results. Eight mega programs were discussed during the meeting with three major expected system-level outputs:

1. Lift productivity and reduce poverty, by increasing annual agricultural productivity by 0.5% to meet the food needs of the future world population and to reduce poverty by 15% by 2025.
2. Contribute to reduction of hunger and improved nutrition, in line with Millennium Development Goal 1 (MDG 1) targets, cutting in half by 2015 (or soon thereafter) the number of rural poor who are undernourished, with a focus on contributing to a reduction in child undernutrition of at least 10%.
3. Contribute to sustainability and resource efficiency, a reduction in the impacts of water scarcity and climate change on agriculture through improved land, agro-forestry, forestry, and water management methods that increase yields with 10% less water, reduce erosion, and improve water quality by maintaining ecosystem services.

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Concurrent Session Presentations

Theme 1: Current Status of Climate Change in the Dry Areas: Simulations and Scenarios Available

Analysis of Jordan vegetation cover dynamics using MODIS/NDVI from 2000 to 2009

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Abstract

Jordan has been affected by frequent droughts in the last few years. A Moderate Resolution Imaging Spectroradiometer (MODIS) - Normalized Difference Vegetation Index (NDVI) time series 2000-2009, 1 km resolution, was used to extract the NDVI values of a 10 km buffer area for twelve meteorological stations representing the rainfed cultivated areas of Jordan. The objective of this study was to investigate the vegetation dynamics within seasons, and stations as an indication of climate change. The average annual NDVI values for the different stations tend to follow a similar pattern through the growing season that extends from November to May. It reflects that there is a decrease in precipitation from West to East and from North to South. Results of Pearson correlation analysis showed a significant response of monthly NDVI to cumulative rainfall. A threshold method was developed to determine the onset and the end of the growing season. Results show that in last four years, there is a trend of delay in the start of the growing season, especially in southern Jordan.

Keywords: climate change, Jordan, MODIS, NDVI, remote sensing.

1. Introduction

Jordan has been affected by frequent droughts in the last few years. The country is already known for its arid climate, long dry season and insufficient precipitation (Freiwan and Kadioglub 2008b). The spatial distribution of average annual precipitation over Jordan varies from region to region. Precipitation decreases from West to East and from North to South reaching approximately zero in the South-east (Dahamsheh and Aksoy 2007).

Under arid and semi arid climatic conditions, vegetation growth integrates the effective climatic parameters especially precipitation (Schmidt and Karnieli 2000; Weiss et al. 2004b; Anyamba and Tucker 2005). Time-series of the Normalized Difference Vegetation Index (NDVI) are widely used to study vegetation index correlation with precipitation (Schmidt and Karnieli 2000; Al-Bakri and Suleiman 2004; Weiss et al. 2004a; Weiss et al. 2004b; Piao et al. 2006; Bajgiran et al. 2007; Wardlow and Egbert 2008) regional growth variation (Ramsey et al. 1995; Al-Bakri and Suleiman 2004; Weiss et al. 2004b; Chandrasekar et al. 2006; Heumann et al. 2007; Wardlow et al. 2007), seasonal and inter-annual dynamics (Senay and Elliott 2000; Hill and Donald 2003; Yu et al. 2003; Weiss et al. 2004a; Barbosa et al. 2006; Salim et al. 2007; Telesca et al. 2008) and as an indicator of ecological and climatic change (Pettorelli et al. 2005; Linderholm 2006; Piao et al. 2006; Zhongyang et al. 2008).

NDVI is calculated from the visible and near-infrared light reflected by vegetation and is defined as: $(NIR - RED) / (NIR + RED)$. The index can range from -1.0 to 1.0, but vegetation values typically range between 0.1 and 0.7. Different NDVI data sets are available, with different spatial and temporal resolutions, and different temporal coverage such as LANDSAT, SPOT, NOAA AVHRR, and any other sensor that operates in red and NIR bands. The Moderate Resolution Imaging Spectroradiometer (MODIS) provides a better quality, but short-term NDVI time-series, (250–1000 m resolution), extending from the year 2000 to the present (Zhang et al. 2003; Pettorelli et al. 2005; Brown and de Beurs 2008; Karlsen et al. 2008).

After smoothing the properties, the NDVI time-series can be summarized in a variety of related indices. For example, measures include the rate of increase and decrease of the NDVI; the annual maximum NDVI; the dates of the beginning and the end and peak(s) of the growing season; the length of the growing season; and the NDVI value at a fixed date (Senay and Elliott 2000; Bai, et al., 2005; Pettorelli et al. 2005; Barbosa et al. 2006; Brown and de Beurs 2008).

Previous studies have described a variety of methods that have been developed over the past decade to detect the timing of vegetation phenology from satellite data (Zhang et al. 2006; Zhongyang et al. 2008). The simplest approaches to estimate the start and the end of the growing season use prescribed thresholds of NDVI values (Chen et al. 2000; Shutova et al. 2006; Karlsen et al. 2008; Upadhyay et al. 2008). These methods can work well at local scales and for specific vegetation types (Zhang et al. 2006). No such study was done for Jordan previously.

Rainfed agriculture in Jordan is highly related to the start of the rains, and the length of the rainy season, which differ from region to region. This issue is of great importance when planning agricultural operations (Sivakumar 1988), especially sowing dates. Regional differences in vegetation and length of the growing season are associated with the climatic gradients of these regions (Heumann et al. 2007; Karlsen et al. 2008). The vegetation growing season are characterized by four transition dates, which correspond to key phenological phases: (1) green-up: the date of onset of greenness increase; (2) maturity: the date at which canopy greenness approaches its seasonal maximum; (3) senescence: the date at which canopy greenness begins to decrease; and (4) dormancy, the date at which canopy greenness reaches a minimum (Zhang et al. 2003; Zhang et al. 2006).

The objective of this study was to investigate the vegetation dynamics of rainfed cultivated areas of Jordan within seasons, and stations as an indication of climate change using a time series MODIS-NDVI 2000-2009 (1 km resolution).

2. Material and methods

2.1. Study area

Jordan is located between 29º 11' N and 33º 22' N latitude, and between 34º 19' E and 39º 18' E longitude with an area of more than 89 000 km^{2}.

Most of the rain in Jordan falls between December and March, with high variability in intensity and duration of each event. Generally, growing season extends from November to May with regional variations. In a previous work (Al-Naber et al. 2009), a MODIS time series 2001-2007 1 km was used to classify and stratify Jordan vegetation cover, into 15 major vegetation signatures with similar NDVI properties using digital automatic grouping or clustering techniques of the unsupervised Iterative Self-Organizing Data Analysis Techniques (ISODATA) algorithm (Chen et al. 1999; Jakubauskas et al. 2002; Al-Bakri & Taylor 2003). Later, these signatures were edited and evaluated to merge the number of classes from 15 to 10, based on supervised classification with Maximum Likelihood Classifier (MLC) (Fig.1).

Generally, the ten vegetation classes were able to separate the different vegetation strata and showed good response to rainfall distribution in the country (Al-Naber et al. 2009). Classes 8, 9, and 10 were able to represent Jordan's most promising cultivated areas of the steppe range, rainfed Mediterranean, and sub humid Mediterranean zones, respectively.

In this study, twelve meteorological stations were selected covering the rainfed cultivated areas of Irbid, Ramtha, Mafraq, Ras Muneef, Jarash, Salt, Madaba, Queen Alia International Airport (QAI Airport), Rabbah, Mutah, Tafileh and Shoubak. The characteristics of these stations are presented in Table 1. The spatial distribution of these stations corresponds to precipitation variation from West to East and from North to South.

2.2. Satellite images

The time series of the MODIS/TERRA Vegetation Indices16-Day L3 Global 1km Sin Grid, V005, for the period 2000-2009 were downloaded from the

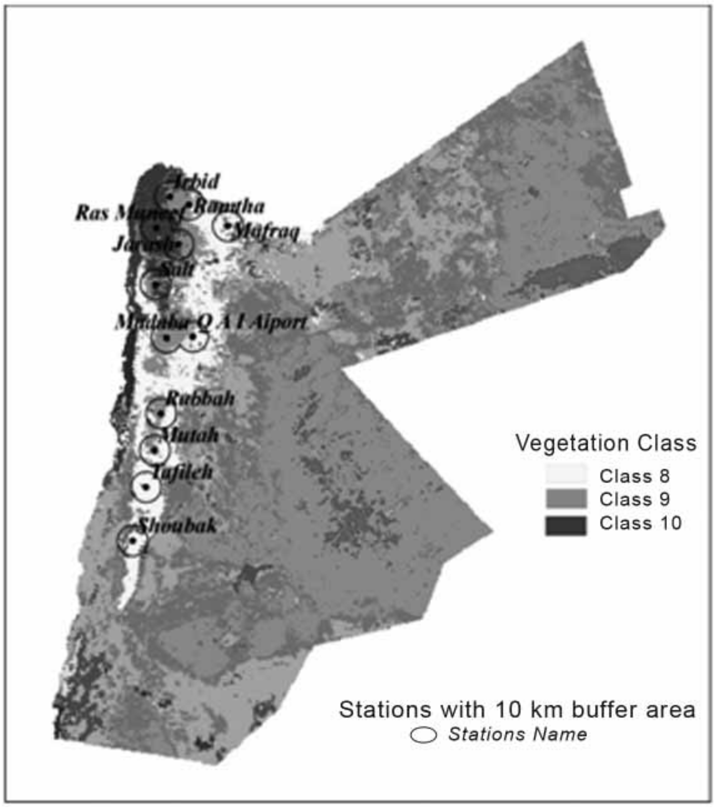

Figure 1. Major vegetation classes of Jordan produced using supervised classification MLC, for a MODIS-NDVI time series 2001-2007 1 km (Al-Naber et al. 2009). Meteorological stations used in this study are indicated with a buffer of 10 km.

Table 1. Characteristics of study stations

Station	Elevation (m)	Longitude**	Latitude	Mean annual rainfall (mm)	Land use
Irbid	616	767625	3604985	471.6	Rainfed (R) Crops (C)
Ramtha	590	780306	3599782	221.0	RC and Range (Rng)
Mafraq	686	805822	3585725	161.3	R Barley and Rng
Ras Muneef	1150	758756	3584405	686.9	Forest (F) & Orchards (O)
Jarash	540	773175	3573687	NA	F & O
Salt	796	758128	3547398	551.5	F & O
Madaba	785	765333	3512441	350.2	RC & O
Q A I Aiport	722	782712	3512903	176.8	R Barley and Rng
Rabbah	920	761845	3462419	335.6	RC
Mutah	1105	757669	3438276	340.5	RC
Tafileh	1260	751872	3414099	238.5	RC, O, & Rng
Shoubak	1365	743097	3378769	311.6	O, RC, and Rng

Score of Date : Jordan climateto Chimatophical Handbook (2000)
** Projected coordinate system:WGS 1984 UTM zone 36 N

NASA Website (https://wist.echo.nasa.gov/api/). Jordan is covered by two granules, h21v05 and h21v06.

2.3. Image processing

The images were in standard HDF format. The data set included the NDVI composite of maximum values for every 16 day, which were imported into image format (img) using the ERDAS Imagine software. Image processing techniques included mosaic of the two granules of NDVI images to cover Jordan. For each year, a total of 23 images were stacked. The images were re-projected to the UTM standard projection using zone 36. A circle of 10 km diameter was used as buffer area to extract the NDVI values, as spectral profiles representing the corresponding station. The extracted profiles were then arranged in spreadsheets to carry out further analysis.

2.4. Meteorological data

Climatic data represented by long term - monthly precipitation for 8 of the 12 stations (Irbid, Mafraq, Ras Muneef, Salt, QAI Airport, Rabbah, Tafileh and Shoubak) were provided by the Jordan Meteorological Department and the Ministry of Agriculture.

2.5. Methodology

Mean NDVI values for each station: This value was calculated for each of 215 dates (of the 16 day image), from over 400 pixels, for the period from 18 Feb 2000 till 25 June 2009.

Average seasonal NDVI value and average seasonal coefficient of variation (CV%): The 215 means were rearranged into nine seasons (29 Aug – 13 Aug) (2000/2001- 2008/2009). The nine season-averages were calculated for 23 different periods, for each of the twelve stations through the growing season.

Monthly NDVI: These values represent the NDVI values of the last day of the month, and were calculated from respective two images, using deviation between two consecutive NDVI values and number of days, using the following formula

$$([(NDVI_j-NDVI_i)/16] \times \text{number of days}) + NDVI_i$$

Pearson correlation: It was determined between monthly NDVI value and monthly cumulative rainfall for 8 stations, Irbid, Mafraq, Ras Muneef, Salt, QAI Airport, Rabbah, Tafileh and Shoubak. Threshold value: Since there is no previous study done for Jordan, several iterations were tried to develop a threshold method that can determine the onset and end of the growing season, and that is acceptable for the twelve stations in this study.

New adjusted NDVI values were calculated using the following equation

$$NDVI_{Adjusted}=NDVI_{ij} - NDVI_{minj} / Std_j$$

where NDVIij is mean NDVI value for date(i), in season(j); NDVImin(j) is the average minimum NDVI value representing the dormancy phase of season (29 August to 14 October of first season and 12 July to 13 August of second season); Stdj is the Standard Deviation of mean NDVI values for that season, and the threshold value adopted as the time when the threshold value was 0.3 for both beginning and end of season.

Peak of season and peak NDVI value: Peak-of-greenness is the period when the maximum NDVI occurred. This value is an indicator of the greenness of vegetation during the season.

3. Results and discussion

3.1. Average seasonal NDVI value

The nine-season average NDVI for the twelve stations generally display uniform behavior through the growing season (Fig. 2), which usually starts by November and ends around the end of May. Stations of North West record highest NDVI values, throughout the season, especially Ras Muneef, followed by Jarash, Irbid and Salt Stations as these stations receive highest precipitation values. Lowest NDVI values are recorded in South in Shoubak and in East in Mafraq. Their spatial distribution reflects the decrease of precipitation from West to East and from North to South (Dahamsheh and Aksoy 2007).

Greenness starts in the North West areas, followed by Center and South East areas. Freiwan and Kadioglu (2008b) divided the country into three homogeneous precipitation regions: (1) the northern region, which includes the northern heights, western Amman, Irbid and the extreme northern Jordan Valley (Baqura); (2) the central region which includes part of Amman, the southern heights (Shoubak and Rabbah); and (3) the third region that consists of the northern and southern heights (QAIA,Wadi Duleil and Mafraq), the eastern parts (Safawi and Ruwaished), southern and southeastern parts (Ma'an and Jafr) and southern Jordan Valley extending to Aqaba.

The seasonal maximum NDVI value representing the period of peak growth (maturity) occurs normally in March. Again Ras Muneef, Jarash, Irbid and Salt record highest value. While Shoubak and Mafraq have the lowest records.
The end of season occurs around the end of May, where average NDVI values tend to go back to the starting point. The dormancy period extends through summer from June to October, during which Ras Muneef, Jarash and Salt stations, record the highest values, since the area is dominated by evergreen forests.

The longest seasons occur in North West, in Ras Muneef, Jarash, Salt and Irbid, while the shortest seasons appear in Shoubak and Mafraq.

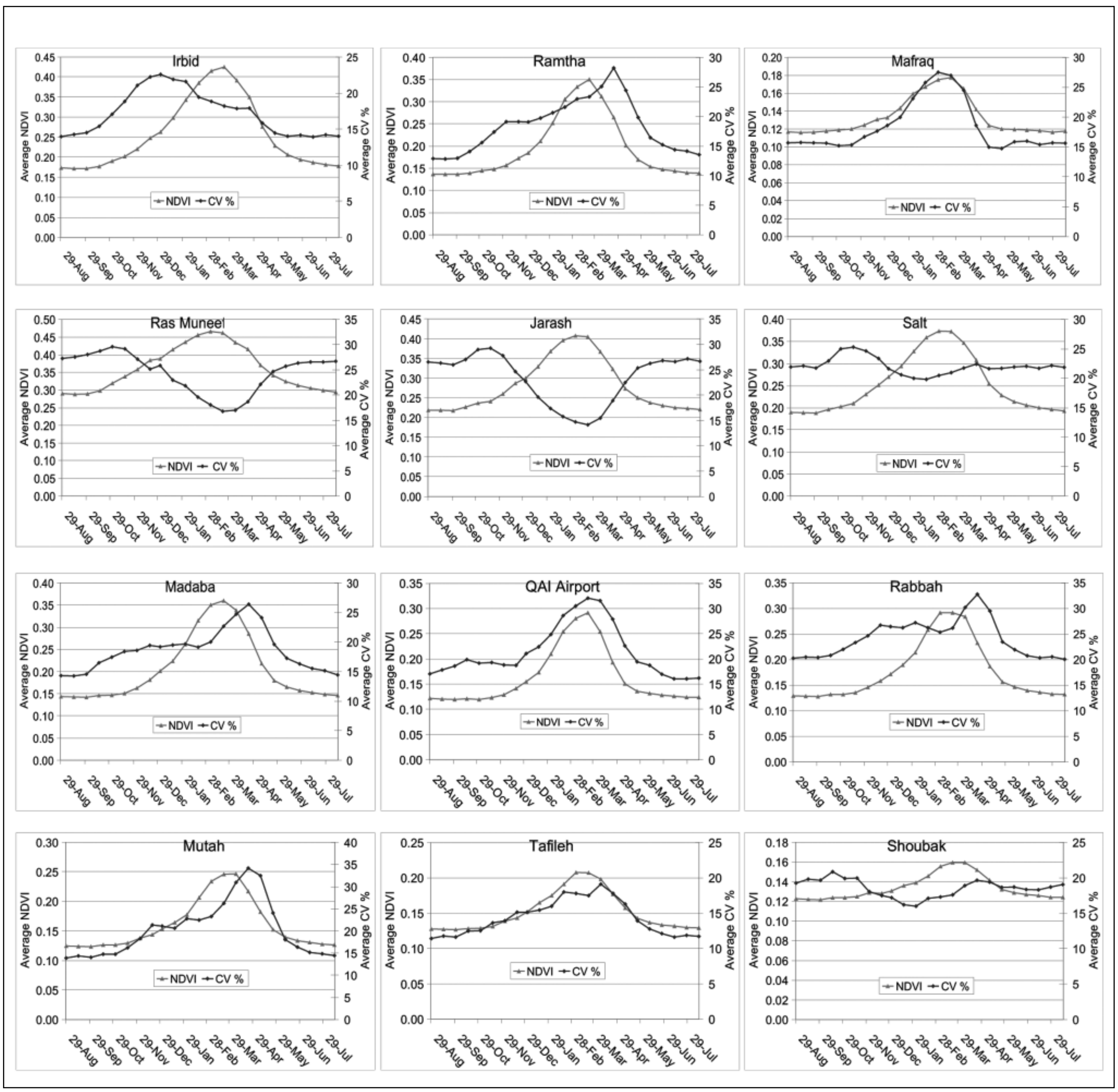

Figure 2. Nine-season average NDVI and CV% for seasons (2000/2001 - 2008/2009).

3.2. Average seasonal CV

Seasonal CV% profiles for Ras Muneef, Jarash have the same pattern, with highest variation from October to December and least variation during peak growth period of spring. This is due to the fact that these areas are highly vegetated, dominated by evergreen forests. High NDVI at the start of season is subject to fluctuation due to variation in onset of rain. As the season progresses, the vegetation gets stabilized and becomes insensitive to small fluctuations in rainfall. Similar results were found by Chandrasekar et al. (2006). Salt and Shoubak have also similar pattern, but with more fluctuations during peak growth period, due to lower and insufficient rainfall amounts.

Stations with lower NDVI values, like Ramtha, Madaba, Rabbah, and Mutah have a different CV% pattern. These areas are mainly cultivated with rainfed cereals, and fall in zones of 200 to 350 mm rainfall. The CV% is uniformly low during summer. With start of the vegetation growth CV% increases and fluctuates due to vegetation growth variation and rainfall received. As NDVI reaches its maximum value the CV% starts to increase again having its peak later after the NDVI peak, which could be attributed to vegetation variations within the same area. Mafraq, QAI Airport and Tafileh stations have a CV% pattern that is uniform with NDVI pattern, where the only variation is due to vegetation growth.

Irbid station has CV% pattern which lies in between the other patterns. CV% increases with season onset, but as the season progresses, and vegetation becomes uniform the fluctuations become less. Irbid lies in the 450-500 mm rainfall zone. Here again, because of high percentage of vegetated area and sufficient rainfall, there is high CV% at the start of the season and it reduces later in the season.

3.3. Correlation between monthly NDVI values and cumulative rainfall

In climate assessment studies, trends are fundamental statistical tools in the detection of climate variability, but time series shorter than 30 years length cannot be considered (Freiwana and Kadioglu 2008a). MODIS-NDVI time series available in this study is only 2000-2009; therefore a trend analysis could not be used. However, the long-term rainfall information available for the 8 stations, Irbid, Mafraq, Ras Muneef, Salt, QAI Airport, Rabbah, Tafileh and Shoubak, were used to derive a linear trend equation (Fig. 3), and was found not significant for all the station. Freiwan and Kadioglu (2008a) found that the inter-annual mean of precipitation reveals insignificantly decreasing Mann–Kendall trends in most stations studied for Jordan.

In order to understand the significance of using NDVI data in climate variability analysis, it was important to study the MODIS-NDVI time series correlation to rainfall. Figure 3 shows the different patterns of cumulative rainfall and the response patterns of monthly NDVI values. The Pearson correlation was found significant at 0.01 level of probability for all the stations. The maximum correlation coefficient was in Salt, Rabbah and Irbid (r = 0.86**, 0.81** and 0.80** respectively). Minimum values occurred in Mafraq (r=0.59**). These results concur with the findings of Al-Bakri and Suleiman (2004) using the NOAA/ AVHRR satellite imagery (1981 to 1992).

Although Ras Muneef station received the highest rainfall amounts, among the stations in this study, it did not show the highest correlation value (r =0.76**). This could be either because the NDVI response to rainfall reached a threshold (saturation response) above which no further response was possible, or the NDVI response to rainfall was non-linear (Al-Bakri and Suleiman 2004; Chandrasekar et al. 2006; Caocao et al. 2008).

3.4. Threshold value analysis

Various studies that determine the onset and end of the growing season using NDVI time series have been calibrated using ground measurements of plant phenology (Chen et al. 2000; Zhang et al. 2006; Shutova et al. 2006; Karlsen et al.2008).

In this study, no field measurements were made. Different approaches used by others in the past, such as mean peak value (Shutova et al. 2006; Karlsen et al. 2008), mean NDVI value (Shutova et al. 2006), or greatest rate of change in NDVI (Upadhyay et al. 2008), were tried but none gave good results. This could be because of the use of mean NDVI values of a none homogeneous areas instead of pixel values.

The multi-temporal NDVI profile would be expected to reflect the phenological characteristics (Wardlow et al. 2007), and since the adjusted NDVI values enhanced the visual inspection, these were used to establish the dates for the onset of season, peak, and end of season (Senay and Elliott 2000). Figure 4 shows that recession of vegetative growth occurred due to low rainfall amounts or delay of rainfall in the early season.
The vegetative growth got initiated with the start of rain, but as the following period did not have adequate rain to meet the essential plant water requirements, a decline in vegetative growth occurred; examples are obvious in early seasons of 2006/2007 and 2008/2009 in Irbid, Ras Muneef, Jarash and Salt. In other stations this led to delay of onset of growing season. Examples were 2007/2008 season in Madaba, 2006/2007 in Ramtha, and 2008/2009 season in Madaba and Ramtha. Stations of QAI Airport, Rabbah Mutah, and Tafileh showed a persisting pattern of season onset delay starting from 2005/2006 to 2008/2009.

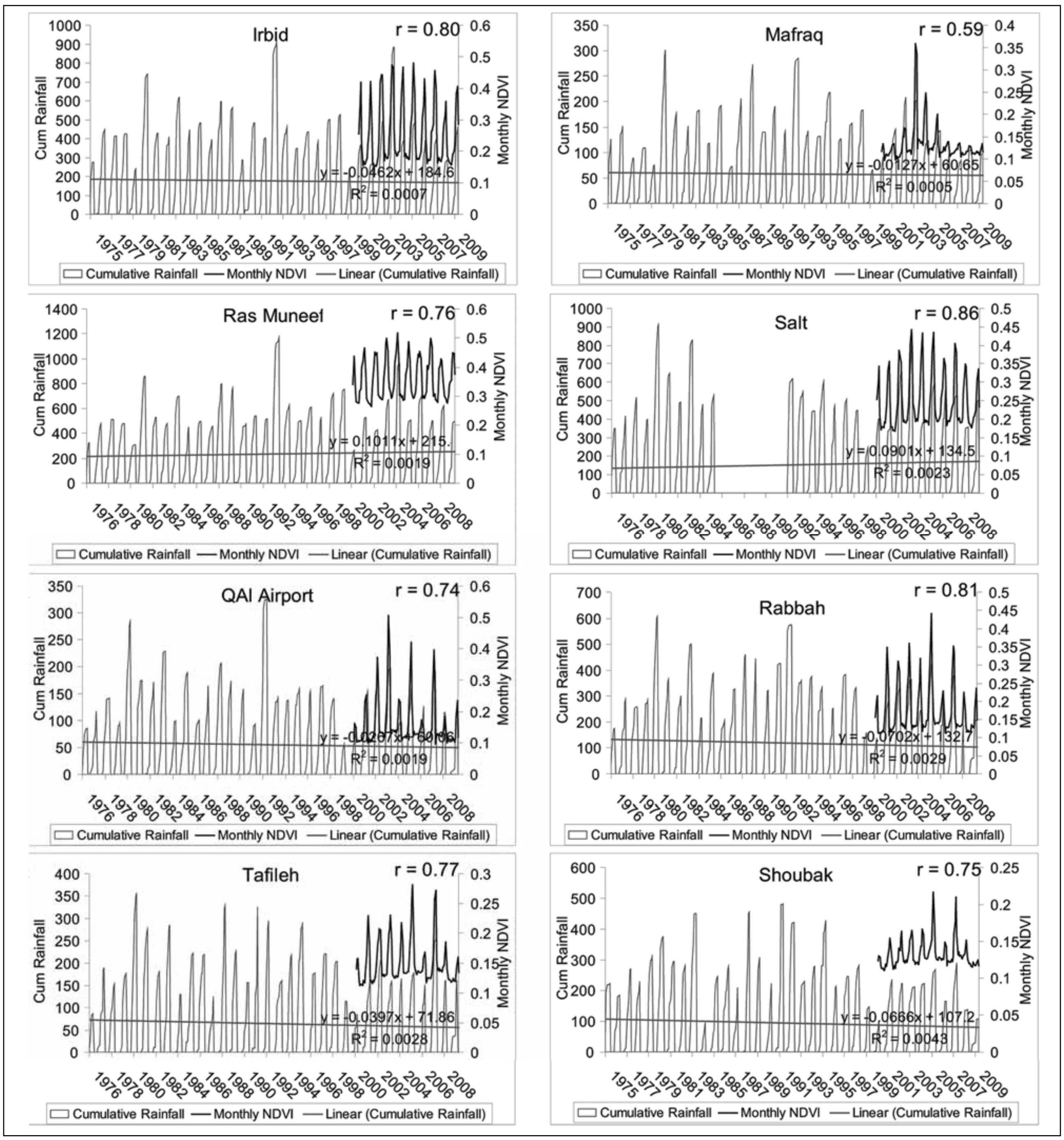

Figure 3. Comparison between cumulative rainfall and MODIS monthly NDVI values, for selected meteorological stations.

Among the stations in this study, Shoubak and Mafraq received the lowest rainfall. Drought and delay of rainy season in these stations resulted in low NDVI pattern that cannot be regarded as seasonal growth pattern. Examples are Mafraq in 2000/2001, and 2005/2006 to 2008/2009 seasons, and Shoubak in 2008/2009 season.

The dates of the 0.3 thresholds for the onset and end of growing seasons were plotted in the curves shown in Figure 5 as was done by other workers (Chen et al. 2000; Yu et al. 2003; Zhongyang et al. 2008).

3.5. Onset of growing season

The curves of the annual onset of growing seasons show the variability between different seasons, as affected by rainfall season start. The stations in North (Ras Muneef, Irbid, Jarash, Salt, and Ramtha) had little variation in the onset date from year to year. Nevertheless, the onset of season 2002/2003 was delayed in all these stations. The onset of seasons 2006/2007 was delayed in Jarash, Salt, Madaba and QAI Airport. Season 2008/2009 was delayed in Ramtha, Jarash, Salt, Madaba and QAI Airport. The onset of seasons 2005/2006

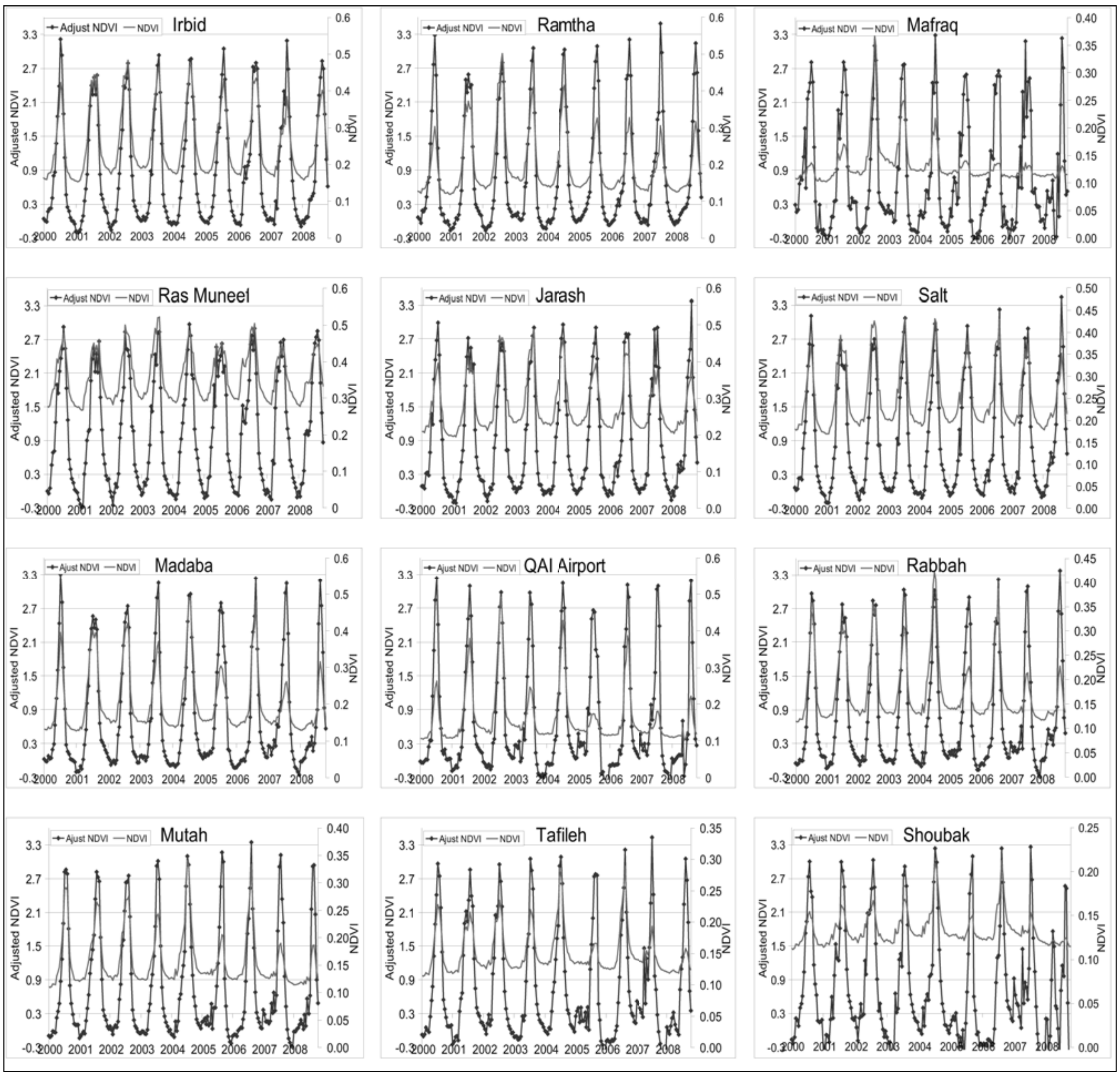

Figure 4. Adjusted NDVI values for different stations, used for determination of the onset and end of the growing season.

to 2008/2009 got delayed in the South (Rabbah, Mutah, Tafileh and Shoubak).

3.6. Peak of season and peak NDVI value

Peak-of-greenness occurred in all stations on 22 March, with a 2-week plus or minus deviation. Nevertheless, some individual variations occurred that can be attributed to delay of rainfall, rainfall amounts and pattern and an early end of rainy season. Peak of season was delayed in the last four years, in the Center and South Jordan (Madaba, QAI, Rabbah, Mutah, Tafileh and Shoubak), in a trend similar to that of the delay of season onset.

Peak of the season or maximum value of growing season provides an index of the greenness of vegetation during the season, and can help in specifying good season from drought ones. Figure 5 indicates that the variation among peak NDVI values for the stations in North was relatively low, but seasons 2002/2003, 2003/2004 and 2004/2005 were the best among the time series, especially in Irbid, Ras Muneef, Jarash and Salt. Stations with lower amounts of rainfall had more variation in peak NDVI in different seasons. For example, season 2002/2003 was specifically good in stations in the West (Mafraq, Ramtha and QAI Airport).

Seasons 2004/2005 and 2006/2007 were the best in Center and South (Madaba, QAI Airport, Rabbah, Mutah, Tafileh and Shoubak), while seasons 2005/2006, 2007/2008 and 2008/2009 were the worst in these areas.

3.7. End of growing season

The curves of the end of growing seasons reflect the end of the rainy season. Nearly all stations showed the same pattern. Season 2001/2002 ended late in most of the stations. Meanwhile season 2000/2001 ended earlier in most of the stations.

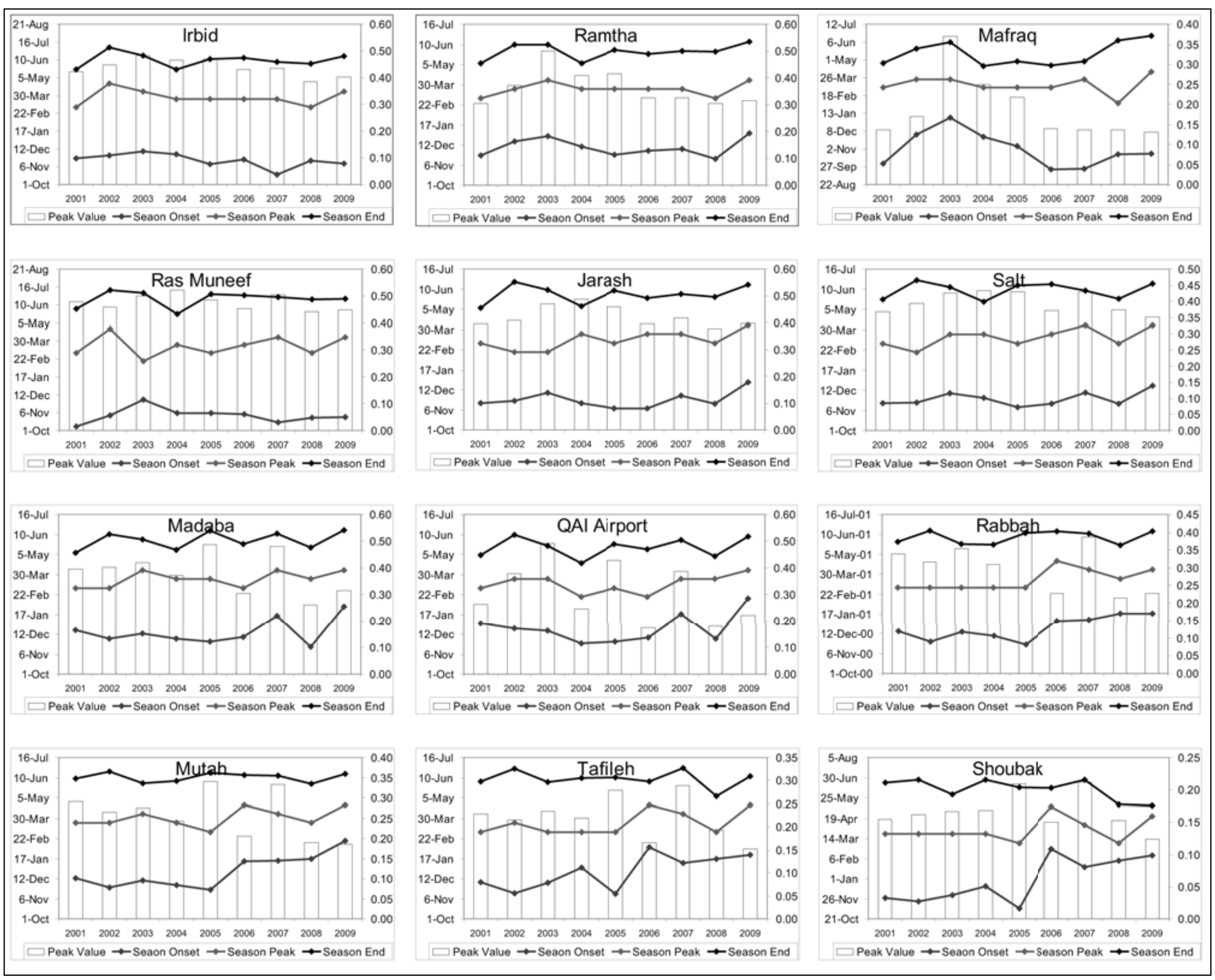

Figure 5. Growing season onset, peak and end dates, and peak value for different stations.

Season 2003/2004 ended early in the North (Irbid, Ramtha, Mafraq, Ras Muneef, Jarash, Salt, Madaba and QAI Airport), while season 2007/2008 ended earlier than usual in Center and South (Salt, Madaba, QAI Airport, Rabbah, Mutah, Tafileh and Shoubak).

4. Summary and conclusions

A MODIS-NDVI time series was used in investigating the vegetation dynamics within seasons, and stations as an indication of climate change.

Based on the nine-season average NDVI profiles and the corresponding CV%, Jordan was divided into three regions, North, Center to South and East (Freiwan and Kadioglu 2008b). The northern region, which receives highest rainfall, recorded highest NDVI values with high CV% at the start of the season. The Center to South and Eastern parts of Jordan with lower and variable rainfall, had lower and variable NDVI values with high CV% around the peak of vegetation growth.

Highly significant Pearson correlation was found between monthly cumulative rainfall and monthly NDVI values in all stations. Although detailed rainfall amounts (daily) would identify the rainfall pattern, periods of drought, can help in justifying the NDVI behavior. A threshold method was developed to determine the onset and the end of the growing season. The North stations had little variation in onset of season, but the South stations showed a delay of the onsets of season in the last four years (2005/2006 to 2008/2009). Although no comparisons have been made between this method and ground observations, it was helpful in understanding the differences between stations and seasons in this study. Further investigation will be done on pixel basis, and using higher resolution data of MODIS 250m.

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Application of IHACRES rainfall-runoff model in semi arid areas of Jordan

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Abstract

With increasing demands on water resources in Jordan, application of rainfall-runoff models can be part of the solution to manage and sustain the water sector. The change in climate is considered as one of the major factors affecting the rainfall-runoff relationships. This paper presents the preliminary results of applying lumped rainfall-runoff models into ephemeral streams in North-East Jordan where the rainfall can show a rapid change in intensity and volume over relatively short distances. IHACRES model (**I**dentification of unit **H**ydrographs **A**nd **C**omponent flows from **R**ainfall, **E**vaporation and **S**treamflow data) can confidently be applied in semi-arid catchments, under arid hydro-climatic zones and storm time steps. The major problem with this application is the limitations of long term continuous observations. However, the results of this study showed a good agreement between effective rainfall and streamflow. Thus this model can be used to predict water flow in cases where no records exist. Further more, complexity of climate attributes in the region can cause errors of runoff estimations.

Keywords: effective rainfall, streamflow, IHACRES, arid regions

Introduction

Rainfall runoff models developers divide rainfall runoff models into three categories: metric, conceptual and physics-based. Metric rainfall-runoff models are the simplest models based on observed data including rainfall and runoff records to characterize the catchment interaction. Conceptual model describes many internal aspects to characterize the catchment interaction. Physics-based model couples mathematical- physical theories and flow equations to achieve precise simulations.

IHACRES model (Jakeman et al. 1990; Jakeman & Hornberger 1993) is a hybrid conceptual-metric model, using the simplicity of the metric model to reduce the parameter uncertainty inherent in hydrological models (Croke & Jakeman 2004).

The main objective of the IHACRES Model is to characterise catchment-scale hydrological behaviour using as few parameters as possible (Littlewood 2003). The model has been applied for catchments with a wide range of climates and sizes (Croke & Jakeman 2004). It has been used to predict streamflow in ungauged catchments (Kokkonen 2003), to study land cover effects on hydrologic processes (Croke & Jakeman 2004; Kokkonen & Jakeman 2001), and to investigate dynamic response characteristics and physical catchment descriptors (Kokkonen 2003; Sefton & Howarth 1998). IHACRES contains a non-linear loss module which converts rainfall into effective rainfall followed by a linear module that transfers effective rainfall to streamflow.

Figure 1 shows the model components. Usually, non-linear loss module within IHACRES includes three parameters. The initial stage of the module calculates the drying rate and the catchment moisture index that increases its flexibility in being used in climate change approach. The linear model employs discrete-time, transfer function, representation of the Unit Hydrograph (UH).

In this study, IHACRES model was applied using daily rainfall, temperature, and streamflow data to predict the streamflow in the north-east Jordan.

Changes in climate could affect the rainfall magnitudes, the drying rates, and the catchment wetness indices in arid regions. This condition can decrease the streamflow magnitudes as well as change the streamflow behaviour.

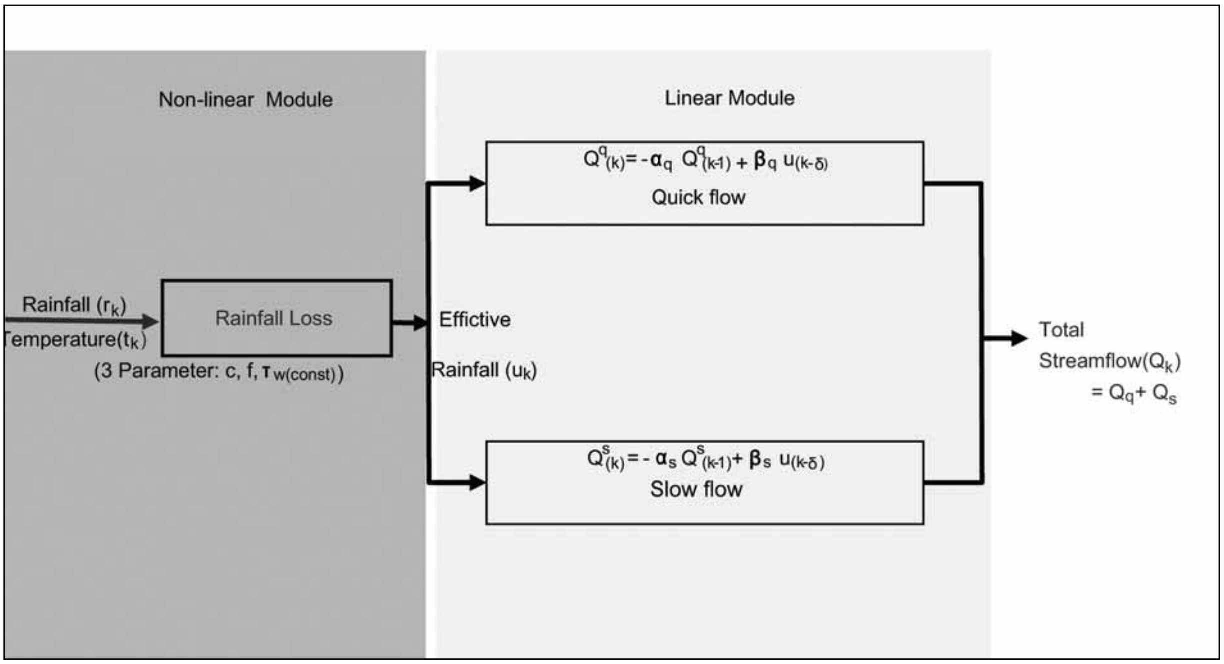

Figure 1. Generic structure of IHACRES model.

Study area

The IHACRES model was applied to Wadi Dhuliel sub-basin in the northeast Jordan catchment. Most of the catchment area belongs to Al-azraq Basin (Fig. 2). The upper part of the catchment area passes over the Syrian border. The catchment altitude varies between 500m in the south and 1400m in the north.

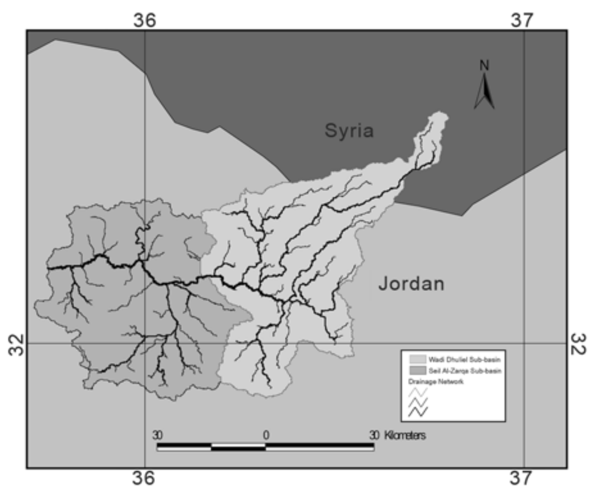

Figure 2. Location map of Al-Zarqa basin: including Seil Al-Zarqa sub-basin and Wadi Dhuliel sub-basin.

The area of interest is approximately 1985 km^2 and has semi arid and arid climates. These climates have warm and dry summer with cold and wet winter. Overall, annual rainfall is around 123mm (Fig. 3). Moreover, the year can be divided into rainy season (from October to April) and dry season (from May to September). The rainfall magnitudes distinctly include a sharp west-east gradient from relatively wet west regions to the arid east (Jordanian desert or Al-Badia).

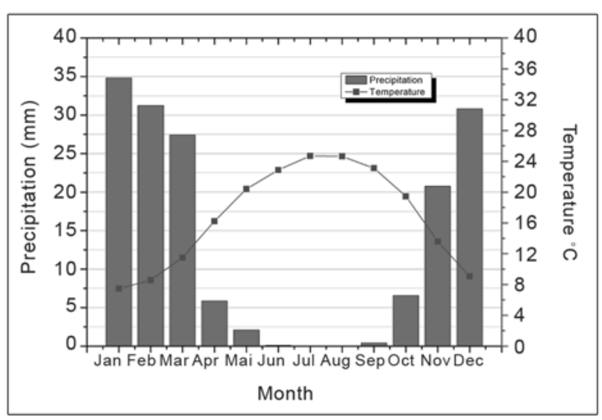

Figure 3. Climograph for Al-mafraq/Northeast Jordan, the period from 1976–2005 (source: Jordan Meteorological Department).

Streamflow in the region is only formed by rainstorms and there is no base-flow affecting the surface streamflow. Apart from short-term projects on streamflow measurements, long-term streamflow data are generally not available for arid sites in Jordan. This may be because of several difficulties such as high cost of equipment, maintenance, materials and transporting personnel, the need for artificial control in the absence of the streambed stability, and turbulence and local effects. The runoff in such dry area tends to be controlled by rainfall intensity and its duration.

Data and method of data analysis

IHACRES model requires three data sets per time unit, rainfall, stream discharge and temperature or potential evapotranspiration. Typical available datasets for arid areas of Jordan are limited to daily rainfall, temperature, and in some cases streamflow records. Rainfall daily data are available from 7 rainfall gauging stations (Fig. 4).

Although there is a significant number of rainfall stations in the study area, unfortunately, they have been only recently added and have inadequate records for describing the general rainfall patterns. Therefore, only 7 rainfall stations' records were utilized for this study. The main characteristics of rainfall stations in the catchment area are shown in Table 1.

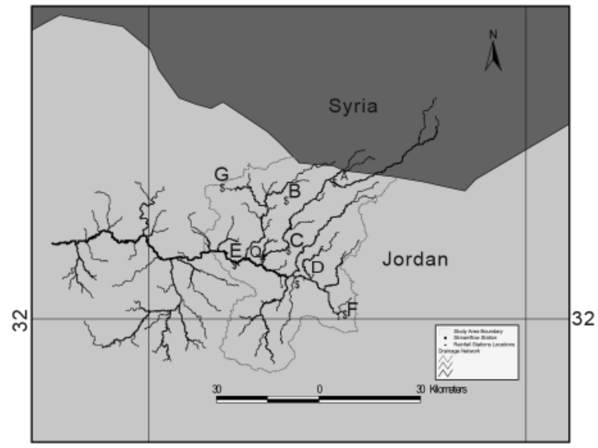

Figure 4. Map of the study area shows the boundary of Wadi Dhuliel sub-basin and the location of the rainfall and discharge stations (Q).

Daily streamflow data were collected between 1986 and 1992 from the sub-catchment streamflow gauging station placed in Wadi Al-Zatari (Fig. 5).

Table 1. Characteristics of study stations

Station code on map (Fig. 4)	Station code in JMWI	Station name	Elevation [m amsl]	Mean annual precipitation [mm]	Recording period	Years
A	AL0058	Sabha and Subhiyeh	843	108.1	1968-2002	35
B	AL0059	Um-Jmal*	670	119.3	1968-2002	35
C	AL0048	Al-Khaldiya	600	125.4	1968-2002	35
D	AL0055	Wadi Dhuleil Nursery	580	137	1968-2002	35 [a]
G	No Code	Almfraq*b	675	158	1975-2005	30
F	AL0049	Qasr Al-hallabat	590	79.2	1968-2002	35
E	AL0012	Sukhnah	556	135.3	1968-2002	35

*Meteorological station; a Missing data in the years 19681971-; b Almafraq station is only the Meteorological station from Jordan Meteorological Department

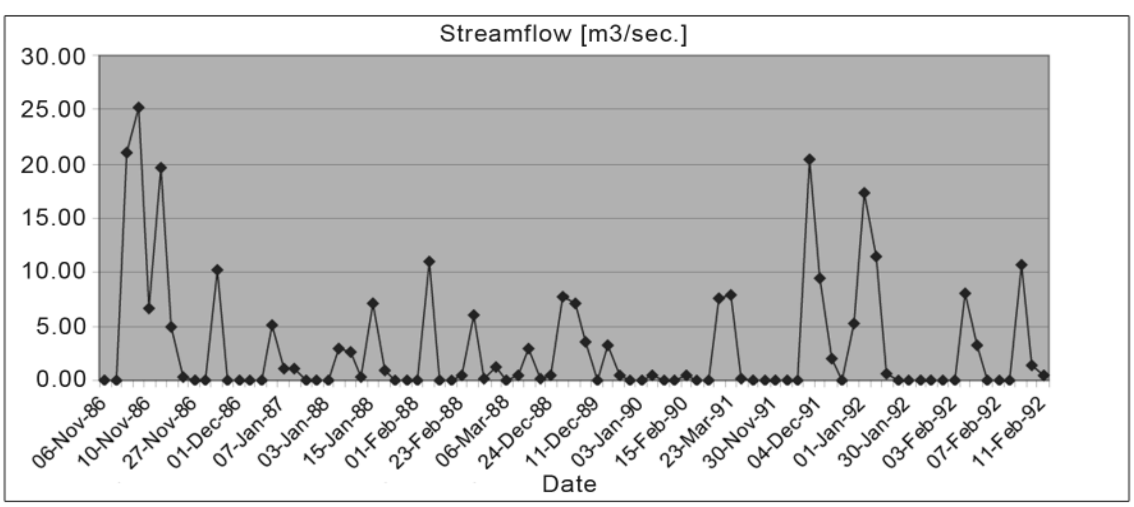

Figure 5. Streamflow records per day from Al-Zatari station (6 Nov1986 - 11 Feb 1992).

The stage-discharge correlation was developed from direct discharge measurements carried out by Jordan Ministry of Water and Irrigation (JMWI) at the gauging station during the first and the second significant rainstorms in November 1986 and January 1987. *In situ* streamflow measurements were based on an integrating method, based on moving the current meter at a uniform speed from the initial point to the next point, taking into account the stream width and observation depth per unit time. Temperature data was obtained from Um-Aljmal Meteorological Station. IHACRES model application was limited to the streamflow measurement period which can be extended for longer term in the future.

Method of data analysis

The original structure of the IHACRES model uses exponential soil moisture drying rate index. Several versions of the model have recently been developed to achieve a good simulation of ephemeral streams in arid regions. In this study the classic redesign (Croke et al., 2005) version has been used. IHACRES model is divided into two modules: non-linear and linear. Rainfall (*rk*) is converted into effective rainfall (*uk*) in the non-linear loss module. In order to obtain the effective rainfall, a catchment wetness index or antecedent precipitation index, representing catchment saturation, is calculated for each time step.

The first step is to determine the drying rate, which is given by:

$$\tau_w(t_k) = \tau_{w(\mathrm{const})} \exp((20 - \mathrm{t_k})\mathrm{f}) \quad \textit{Equation 1}$$

where is the drying rate at each time step, $\tau_{w(\mathrm{const})}$ is time constant, the rate at which $\tau_w(t_k)$ catchment wetness declines in the absence of rainfall. t_k is the temperature at time step k and f is temperature modulation parameter which determines $\tau_w(t_k)$ how changes with temperature. Catchment wetness index S_k is computed for each time step on the basis of recent rainfall and temperature records:

$$S_k = cr_k + (1 - \tau^{-1}_{w(k)})S_{k-1} \quad \textit{Equation 2}$$

where c is the adjustment parameter, is the rainfall at time step k, r_k is time constant, the rate at $\tau_{w(\mathrm{const})}$ which catchment wetness declines in the absence of rainfall.

Finally the effective rainfall (u_k) in the model is given by:

$$u_k = r_k \times S_k \quad \textit{Equation 3}$$

In the linear routing module, the effective rainfall is converted into streamflow (*Qk*). The storage configurations of two parallel storage components have been applied.

$$Q^q_{(k)} = -\alpha_q Q^q_{(k-1)} + \beta_q u_{(k-\delta)} \quad \textit{Equation 4}$$

$$Q^q_{(k)} = -\alpha_q Q^q_{(k-1)} + \beta_q u_{(k-\delta)} \quad \textit{Equation 5}$$

($Q^q_{(k)}$, $Q^s_{(k)}$) are quick and slow streamflow components. The parameters α_q , α_s are the recession rates for quick and slow storage, whereas the parameters β_q , β_s represent the fraction of effective rainfall. The Unit Hydrograph (UH) of total streamflow is the total of both quick and slow flow UHs.

In order to get a representative value, the rainfall dataset was averaged from 7 stations in the catchment area for the same period as archived streamflow data. Based on both datasets, the records were separated into individual storm events to recognize streamflow magnitudes at daily and storm event time steps. Since the catchment is located in arid region, only the significant rainfall records were selected.

Results

Streamflow records from Al-Zatari gauging station (Fig.5) show the main characteristic of streamflow in the area. The runoff coefficient was on average 4.52. The result shows that catchment tends to have very few streamflow events. The simulated streamflow result of the IHACRES model was calibrated over a period from 06.11.1986 to 11.02.1992. Table 2 and 3 list the IHACRES model parameters values and a short summary of drying rate, soil moisture index, and daily streamflow in mm.

The result of IHACRES simulation Model shows poor agreement when applied on daily scale (Fig. 6 and 7) but good agreement when applied on storm event scale (Fig. 8 and 9).

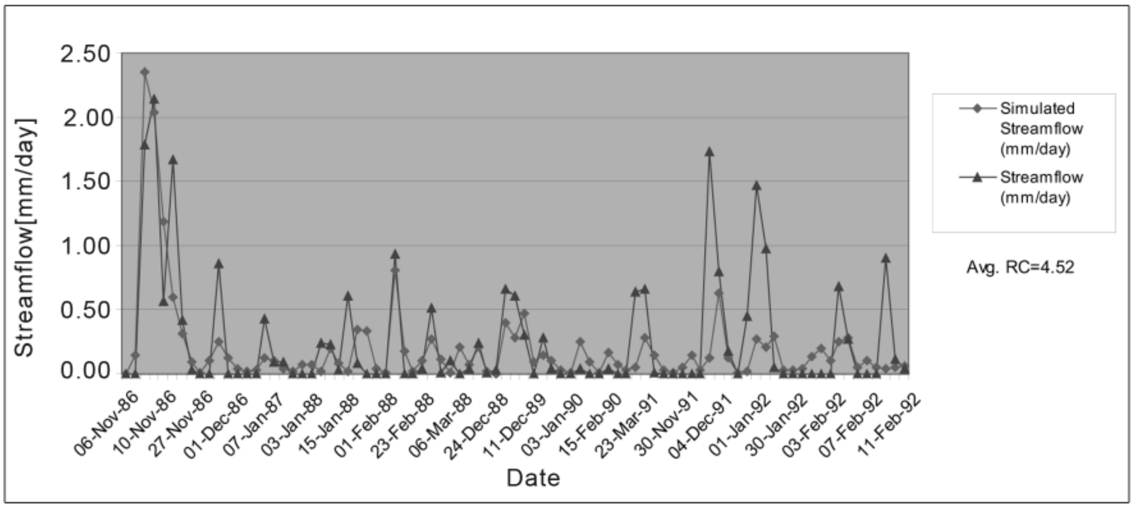

Figure 6. Observed and simulated streamflow (daily scale basis).

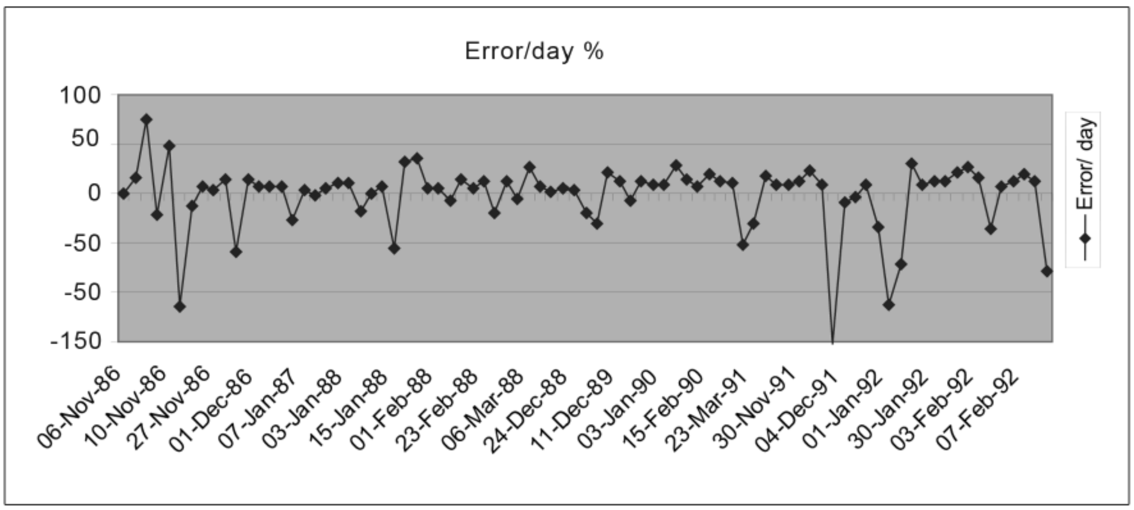

Figure 7. Percent error of daily simulation.

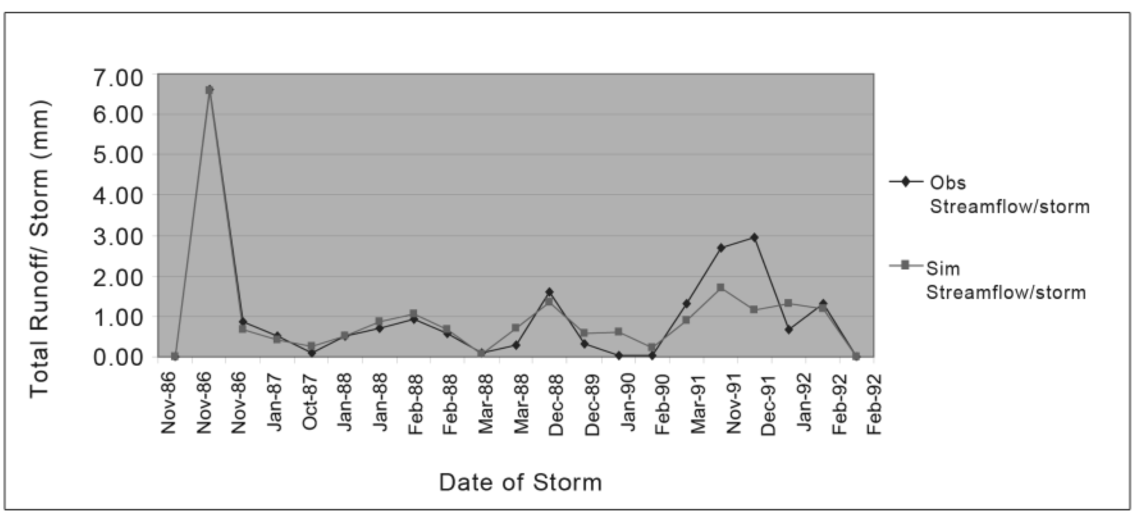

Figure 8. Observed and simulated streamflow (storm scale basis).

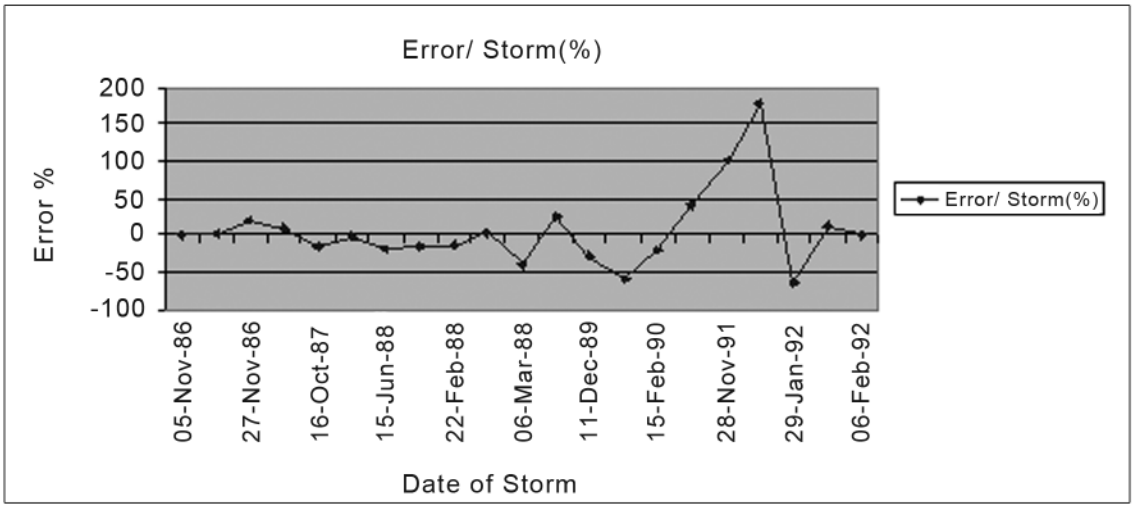

Figure 9. Percent error of storm events simulation.

Table 2. IHACRES parameters

c	0.0042
$\tau_{w(\text{const})}$	4.7
f	0.03
α_q	-0.11
β_q	0.12
α_s	-1
β_s	0

Discussion

It is very difficult to select a rainfall-runoff model for application to an arid region due to many reasons. Lack of hydrological data is likely to increase the dilemma of streamflow simulations in arid regions. Additionally, rainfall behaviour tends to be asymmetric in both space and time, thus affecting the streamflow magnitudes. For these reasons arid catchments are more amenable to simplified models. Because IHACRES is a parametric efficient rainfall-runoff model it is applicable in arid areas, which are dominated by rapid responses to climate variables. Since the model is a lumped model, it has the capability to avoid the spatial variability of the rainfall and streamflow. Furthermore the model requires only few input data.

In general, rainfall-runoff models have many limitations and aim to achieve a moderate accuracy at the best. Errors during simulation often occur because of missing data, or complexity of climate behaviour. The time step calculation is very important for IHACRES modelling in arid region. As the results show, it is very critical to change the calculations from daily time steps to storm event time steps. External data are required to explain the errors in simulation. During the rainy season in the year 1991 the error of streamflow simulation was high, which can be explained by the unanticipated snow storm that covered the area during that season. This storm led to change the entire behaviour of rainfall and temperature gradients. In this case the IHACRES model converted the total precipitation - including snow- into effective rainfall then into streamflow although there was no streamflow because of the freezing condition.

Conclusion

IHACRES rainfall runoff model is applicable in arid areas which are dominated by ephemeral

Table 3. Descriptive statistics

	N	Minimum	Maximum	Mean	Std. deviation
Tw(tk)	85	4.36	8.69	6.5331	0.86832
Sk	85	0.10	1.00	0.2212	0.16818
Streamflow (mm/day)	85	0.00	2.14	0.2613	0.46455

streams and responses to climate variables are rapid. According to the results obtained in this study, the model is able to adequately simulate streamflow in arid catchments when applied on storm events scale. It is not preferable to apply the model on daily basis in arid regions because of the streamflow continuity during the storm events. Changes in rainfall and temperature affect significantly some thresholds; therefore the period for standard calibration of IHACRES models needs to be extended. Longer calibration periods are needed in order to reduce the uncertainty in model parameters and explain climate change effects.

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Generating a high-resolution climate raster dataset for climate change impact assessment in Central Asia and NW China

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Abstract

The contiguous dryland region of Central Asia and NW China is expected to be significantly affected by climate change. In a pivotal and very diverse region, where the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report predicts precipitation increase or decrease depending on the specific location, the coarse-resolution climate change maps provided by Global Circulation Models (GCM) are unable to capture the influence of high-intensity relief. The paper describes the steps taken for generating high-resolution (1 km) maps of future climates in the five countries of Central Asia and the Chinese province Xinjiang. For three different time horizons (2010-2040, 2040-2070, and 2070-2100) four climatic variables (precipitation, and minimum, maximum and mean temperatures) were downscaled to high-resolution gridded datasets based on 17 out of the 23 GCM outputs under three greenhouse gas emission (SRES) scenarios (A1b, A2 and B1). The downscaling method consisted of overlaying coarse-gridded GCM change fields onto current high-resolution climate grids. By automating the map generating process in a GIS environment, 5184 high-resolution maps of future climatic conditions were generated for this dryland region. These maps confirm agreement of the selected GCMs on a significant warming (roughly from +2°C to +5°C by the end of the 21st century) over the whole area, but major disagreement between models on the direction and extent of precipitation changes. The downscaled maps will be aggregated and used for analyzing climate change impacts through changes in agroclimatic zones, growing periods and crop suitabilities.

Keywords: Central Asia, China, climate change, precipitation, temperature.

1. Introduction

Central Asia and the Xinjiang Province of NW China constitute a contiguous dryland area of approximately 5.6 million km^2. Despite an apparent (and misleading) monotony of the landscapes in most of the region, there is a surprising diversity in agroecologies. Moreover, it is a region that has witnessed some major environmental catastrophes and degradation of its land and water resources in its recent past, and is particularly vulnerable to the threat of climate change.

Climate change is expected to affect significantly Central Asian countries in the coming decades. According to the last assessment report of the IPCC (2007), the projected median increase in temperature is estimated to 3.7°C on average by the end of the century, with most of the increase to occur during the summer (June-July-August). Precipitation is projected to increase slightly during the winter and to decrease the rest of the year, which leads to a lower amount of rainfall on annual mean. Heavily watered winters will be more frequent, as well as drier springs, summers and autumns.

Peculiar to Central Asia and NW China is the high upstream/downstream dependency, as the snowfall and glaciers in the mountain chains of the Tien Shan and Pamir are a key to the region's hydrology and agriculture downstream. Consequences of these changes in temperature and precipitation regimes are therefore potentially harmful for the population in this vulnerable area. Food security and water availability are threatened by the increasing water scarcity and higher frequency of drought. Agriculture, which uses 83.6% of the water resources in the region (Abdullaev et al. 2006) and employs a large share of the population (29% according to CIA 2009), will have to adjust in order to cope with increasing stresses and to satisfy a growing population.

In this context, anticipation of climate change impacts and possible pathways for adaptation through scientific research is central for mitigating negative effects. In this perspective ICARDA initiated a project funded by the Asian Development Bank on “Adaptation to Climate change in Central Asia and the People’s Republic of China” (ICARDA 2009), which is aimed at increasing the knowledge about climate change, drought management and adaptation options in the existing agro-ecosystems.

Within the region the projections of precipitation change by the IPCC are mixed (Fig.1). The range in precipitation change may vary indeed from -11% to +16%. Under the considered scenario and model outputs, the expectation for Kazakhstan is a 0-5% increase in the south to a 10-16% increase in the north and east. Kyrgyzstan may expect a 0-10% increase, Turkmenistan and Uzbekistan by contrast lose 0-11%. The picture is mixed in Tajikistan, with a change in the range of -5 to +5%.

These projections come with the well-known uncertainties of climate science in its current state: uncertainty about future GHG emissions (hence the practice of working with change emission scenarios), the use of Global Circulation Models (GCM) which are often in utter disagreement (we will come back to this point later in the paper), and the coarse spatial resolution (typically 1 to 3 degrees) of GCMs, too coarse to include small-scale processes, the ones responsible for local weather patterns (especially in mountain areas). Moreover the IPCC projections in the 4th Assessment Report are for the time frame 2080-99, too far in the future to be meaningful for most of us.

In order to develop climate change adaptation strategies in Central Asia that are meaningful at landscape level, there is a need for ‘downscaling’ climate change from the global to the regional level. This involves an increase in the spatial resolution (e.g. a 10 km^2 grid cell), in order to simulate impact closer to the farmer environment. It also means projecting changes for nearer futures (e.g. 2030, 2050), which are time horizons of interest to local planners for adaptation. Finally there is a need to understand better the seasonal distribution of future precipitation and temperature changes.

This paper details the methodology used for downscaling low-resolution GCM output and transforming these into high-resolution raster maps. We describe successively the following components of this process: data selection and

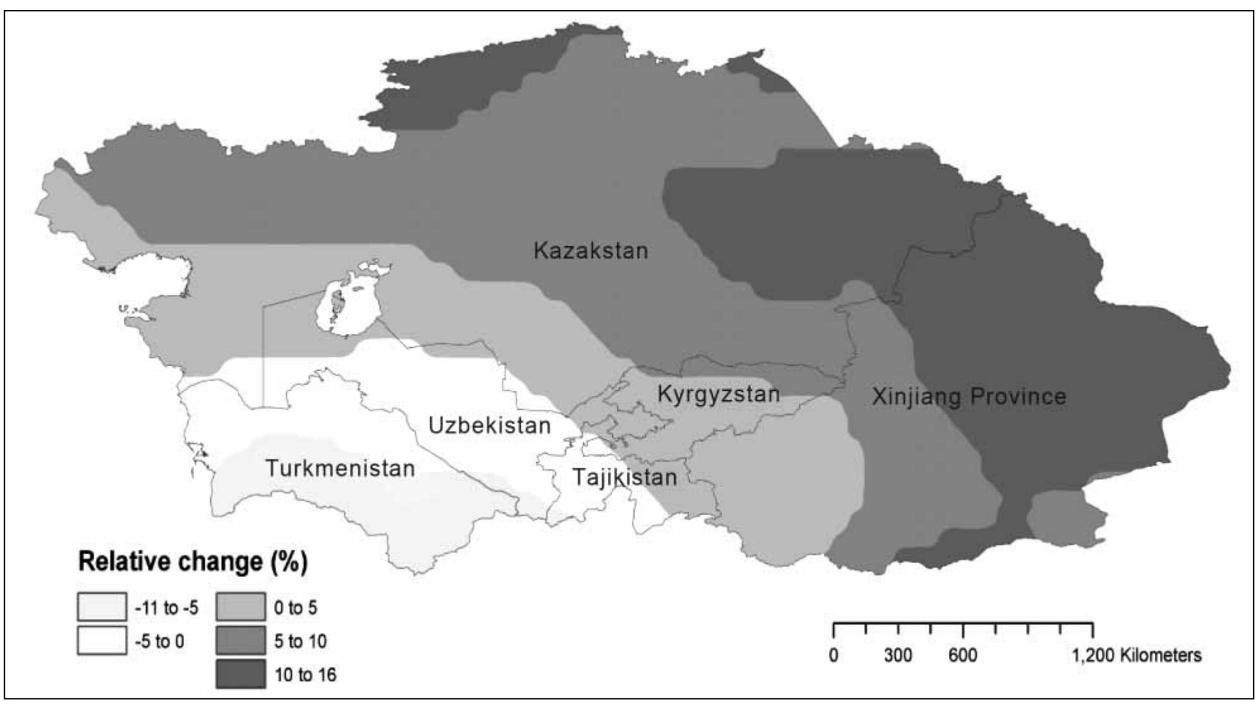


Fig. 1. Precipitation change projections in Central Asia and Xinjiang Province in 2080/2099, according to the average of 21 GCM models under greenhouse gas emission scenario A1b (source: IPCC 2007).

sources, data extraction, data processing, and output description, and add some conclusions and recommendations for follow-up.

2. Methodology

2.1. General approaches for climate change downscaling

Generally speaking, three methods are available for downscaling GCM output to higher resolutions:

- Calibration of current climate surfaces with GCM output,
- Statistical downscaling with or without weather typing and
- Dynamical downscaling with regional models (RCM).

Statistical downscaling yields good results, in terms of reproducing current climates from GCMs. They can be applied to output of different GCMs. On the down side, statistical relationships have to be established individually for each station and GCM, requiring quality data. Surfaces have to be created from point data, a problem in data scarce regions. Moreover, this method is computationally challenging.

The dynamical downscaling using a RCM yields the best results, even in areas with complex topography, and directly generates climate surfaces. It is the only technique able to model complex changes of topographical forcing.

Different methods of dynamical downscaling are linked to specific GCMs, thus transferring inherent flaws in particular models from a lower to a higher resolution. They are also methodologically and computationally challenging.

In this study we use the first method of GCM downscaling, which involves essentially the superposition of a low-resolution future climate change field on top of a high-resolution current climate surface. Four climatic variables were considered: precipitation and minimum, maximum and mean temperatures. Climate change as represented by these variables was assessed for three time horizons: 2010-2040, 2040-2070, and 2070-2100.

2.2. Greenhouse gas emission scenarios

The three most commonly used scenarios were considered in this study: A1b, A2 and B1. The following description of these scenarios is taken from IPCC (2007):

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The A1b scenario assumes a balance between fossil-intensive and non-fossil energy sources, where balance is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies.

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

2.3. Global circulation models

The IPCC report is based on 23 global circulation models (GCM). As some of the necessary climatic variables were not available on-line, only 17 GCM models were selected for this study. The minimum requirement for a GCM output dataset to be selected was the availability of mean temperature and precipitation data for the three scenarios and the three time horizons.

Among the 23 GCMs used in the IPCC report, the seven listed in Table 1 have complete publicly available datasets for precipitation, and maximum, minimum and mean temperatures. For the 10 GCMs listed in Table 2, full precipitation and mean temperature datasets were available.

Data were incomplete for the following IPCC GCMs: MIROC3.2 (hires), GISS-AOM, UKMO-HadGEM1, GISS-EH, FGOALS-g1.0, BCC-CM1. These were not included in the study.
Tables 1 and 2 specify the methods used in the GCMs for air flow parameterizations over orographic features. Given the coarse resolutions of GCMs they use simplified representations of the earth surface. As a result GCMs underestimate greatly high altitudes in steep areas, and subsequently their influence on air flow, temperature and moisture. Our study area includes two of the highest mountain ranges of the world, the Tian Shan and the Pamir Mountains, both with peaks above 7000m. The way the atmosphere over orography is modeled might therefore affect significantly the simulation of both precipitation and temperature regimes. The most common aim of these air flow parameterizations is to transfer the momentum from the earth surface to the atmosphere by orographic waves and/or to force air flow to lift up when it is blocked at the feet of orographic features. The gravity wave drag reduces (suppresses in few cases) the cold bias at high latitudes near the tropopause (IPCC 2007).

2.4. GCM Data sources

Three main websites are devoted to the distribution of the IPCC datasets. The first one is

Table 1. GCM characteristics (1) (source: CMIP3 2007).

Name	Institution	Year	Atmosphere resolution	Parameterization over orographic features
BCCR-BCM2.0	Bjerknes Centre for Climate Research, Norway	2005	2.8° x 2.8° x 31 levels	Subgrid scale orographic drag module to simulate the influence of small scale relief on atmospheric momentum
CSIRO-MK3.0	Commonwealth Scientific and Industrial Research Organization, Australia	2001	1.9° x 1.9° x 18 levels	Gravity wave drag (GWD) formulation of Chouinard et al. (1986). This drag is dependent on the sub-grid-scale variations in surface topography
INM-CM3.0	Institute for Numerical Mathematics, Russia	2004	4° x 5° x 21 levels	Orography gravity wave drag (Palmer et al, 1986)
MIROC3.2 (medres)	Center for Climate System Research, JAMSTEC, Japan	2004	2.8° x 2.8° x 20 levels	Internal gravity wave drag McFarlane (1987)
CGCM3.1(T47)	Canadian Centre for Climate Modelling and Analysis, Canada	2005	3.75° x 3.75° x 31 levels	Orographic drag parameterization (Scinocca and McFarlane 2000)
CGCM3.1(T63)		2005	2.8° x 2.8° x 31 levels	Orographic drag parameterization (Scinocca and McFarlane 2000)
CNRM-CM3	Meteo France, Centre de Recherches Météorolog.	2004	2.8° x 2.8° x 45 levels	No gravity drag mentioned

Table 2. GCM characteristics (1) (source: CMIP3 2007).

Name	Institution	Year	Atmosphere resolution	Parameterization over orography
ECHAM5/ MPI-OM	Max Planck Institute for Meteorology, Germany	2003	1.9° x 1.9° x 31 levels	GWD according to Lott and Miller, 1997: momentum transfer from the earth to the atmosphere accomplished by orographic gravity waves, and drag exerted by the subgrid-scale mountain when the air flow is blocked at low levels
CCSM3	National Center for Atmospheric Research, USA	2005	1.4° x 1.4° x 26 levels	No gravity drag mentioned
PCM		1998	2.8° x 2.8° x 26 levels	No gravity drag mentioned
GFDL-CM2.0	Geophysical Fluid Dynamics Laboratory, USA	2005	2.0° x 2.5° x 24 levels	No gravity drag mentioned
GFDL-CM2.1		2005	2.0° x 2.5° x 24 levels	No gravity drag mentioned
IPSL_CM4	Institut Pierre-Simon Laplace, France	2005	2.5° x 3.75° x 19 levels	GWD according to Lott and Miller, 1997: momentum transfer from the earth to the atmosphere accomplished by orographic gravity waves, and drag exerted by the subgrid-scale mountain when the air flow is blocked at low levels
UKMO-HadCM3	Hadley Centre for Climate Prediction and Research, UK	1997	2.5° x 3.75° x	No gravity drag mentioned
ECHO-G	Meteorological Institute of the University of Bonn, Meteorological Research Institute of the Korea Meteorological Administration, and Model and Data Group, Germany/Korea	2005	1.9° x 1.9° x 19 levels	No gravity drag mentioned
GISS-ER	NASA – Goddard Institute for Space Studies, USA	2004	2.8° x 2.8° x ?	Physically-based estimate of gravity-wave drag detemined from the model simulation of moist convection, mountain waves, shear and deformation (Rind et al, 1988).
MRI-CGCM2.3.2	Meteorological Research Institute, Japan	2003	2.8° x 2.8° x 30 levels	No gravity drag mentioned

the IPCC data distribution portal[1] , where averages over each slice of 30 years are provided for each month. The second one is the WCRP CMIP3Multi Model data portal[2] , which gathers daily values and monthly and yearly averages for most GCMs. Most of these files can also be downloaded from the Earth System Grid (ESG) website[3].

Finally, datasets from certain GCMs, such as CNRM-CM3 and ECHAM5, can also be found at

[1]http://www.ipcc-data.org/
[2] http://esg.llnl.gov:8443/home/publicHomePage.do
[3] http://www.earthsystemgrid.org/

the Model and Data website[4] hosted by the Max Planck Institute for Meteorology in Hamburg.

In some cases where complete datasets could not be obtained from any of the above web sites, missing files could be found on the website of the institute that developed the GCM.

2.5. GCM data processing

The transformation of GCM data into high-resolution climate maps is no trivial matter and required the following steps, which are explained in the following sections:

- Data extraction procedures
- Change mapping at coarse resolution
- Resampling
- Correcting the precipitation maps
- Generating downscaled climate surfaces
- Calculating averages
- File name coding

2.5.1. Data extraction procedures
Datasets for each GCM were retrieved from the sources mentioned above in a NetCDF format (.nc), a self-describing format for weather and climate data files, developed by UCAR[5] . 'Self-describing' means that a header describes the layout of the rest of the file, in particular the data arrays, as well as arbitrary file metadata in the form of name/value attributes. This file structure is particularly suitable for creating, accessing and sharing array-oriented scientific data across networks with multiple platforms and software. The relevant data were extracted from these files using the program GrADS[6] (for Grid Analysis and Display System), which runs under Linux platforms.

The specific extraction procedure depended on the type of datasets. Data from the IPCC data portal website were merely extracted without any additional averaging. Monthly data from the ESG website were averaged over 30 years for the three periods of interest. Daily data were first averaged over the months of each year, and then averaged over each set of 30 years.
Some datasets had a calendar format incompatible with GrADS. This concerns (partly or entirely) the following GCMs: CSIRO-MK3.0, CGCM3.1 T47 and T63, PCM and GISS-ER. In order to render them compatible, the descriptor files of these datasets were modified using the programs Ncdump and Ncgen[7] . Since the data extraction was based on day numbers rather than dates, calendar options could then be simply ignored. For datasets containing different runs without average, averaging over the different runs was done in the GIS software ArcGIS[8].

In order to save downloading time and disk space, some data were only downloaded for one quarter of the globe (0-90°N, 0-180°E), for example the daily data for the two Canadian GCMs (CGCM3.1 T47 and T63).

2.5.2. Change mapping at coarse resolution
After computing every monthly average for each climatic variable, GHG scenario and time horizon, the averages were subtracted by the grid of the 1961-1990 time period (also a GCM output) in the case of temperature data. In the case of precipitation data, the ratio was computed.
For mean, minimum and maximum temperature (Celsius): $\Delta T = T_{LR,21} - T_{LR,20}$
For precipitation (dimensionless):
$r_{prec} = P_{LR,21} / P_{LR,20}$

with LR: low-resolution, 20: 20th century data, 21: 21st century data.

The change in temperature is thus expressed in absolute terms, while the change in precipitation is relative. Change mapping was carried out in GrADS for compatible temperature data, and in ArcGIS in the case of non-compatible temperature formats and precipitation.

2.5.3. Resampling
In order to refine the coarse climate change maps, a resampling was carried out down to a resolution of 0.008333 decimal degrees (about 1km). This resolution corresponds to that of the reference climate maps of the study area.

The resampling was done using the cubic convolution method. With this method, new pixel values are computed based on a weighted average

[4]http://www.mad.zmaw.de/projects-at-md/ensembles/experiment-list-for-stream-1/
[5]http://www.unidata.ucar.edu/software/netcdf/
[6]http://www.iges.org/grads/
[7]http://www.unidata.ucar.edu/software/netcdf/workshops/2009/utilities/NcgenNcdump.html
[8]http://www.esri.com/software/arcgis/index.html

of the 16 nearest pixels of the original map (4 by 4 window). This method is relatively time-consuming, but it offers a smoother appearance than other available methods (nearest neighbour or bilinear interpolation). Possible edge effects (where the 16 pixel values are not all available) were avoided by selecting an area of interest larger than the study area. In our case the resampling of the climate change maps was carried out in ArcGIS over the rectangle 32°-58°N x 44°-98.5°E. Given the large number of coarse gridded change maps, the resampling process was automated by use of a Visual Basic script.

2.5.4. Corrections of precipitation maps
As we used a ratio to represent the change in precipitation, corrections of the coarse-gridded change maps were needed in two cases.

GCMs regularly predicted in some areas an average of 0 mm of precipitation for both the reference period 1961-1990 and the future period under consideration. Calculating the precipitation ratio would therefore lead to indeterminate expressions. To counter this problem, precipitation was assumed not to be lower than a certain threshold value, which in our case was fixed at 0.0167 mm (or $6.43*10^{-8}$ kg m^{-2} s^{-1}), corresponding to a total amount of rainfall of 1 mm in 60 years. Values of simulations of both 20th and 21st century that were below 0.0167mm were raised to that value, so that afterwards change could be computed.

A second issue is that the cubic convolution method for resampling sometimes produces negative values of relative change when the original values are close to 0 mm. The solution to obtain only positive values was to resample using the logarithm of the original values, and obtain the final change grids by exponential transformation of the latter layers. In both cases, thresholding for no-rainfall in both time periods and resampling using logarithmic transformation, Visual Basic scripts were used to automate the process.

2.5.5. Generating downscaled climate surfaces
Downscaled high-resolution (1 km) climate surfaces were obtained by adding the resampled change maps to high-resolution reference climate surfaces (De Pauw 2008) for temperature variables, and by multiplying for precipitation. The mask for Central Asia and Xinjiang was used to restrict these computations to the study area.

The calculations were performed in ArcGIS using simple raster algebra according to the formulas:

- For mean, minimum and maximum temperature (°Celsius): $T_{HR,21} = T_{HR,20} + \Delta T_{resampled}$

- For precipitation (mm): $P_{HR,21} = P_{HR,20} * r_{resampled}$

with HR: high resolution.

Also this process step was automated by means of a Visual Basic script.

2.5.6. Calculating averages
Finally, averages were computed for the resampled high-resolution change maps of precipitation and mean temperature. Averages were made over the year, the winter and the summer for each GCM, scenario and time horizon.

The winter period covers the months December, January and February, while the summer covers June, July and August. The objective of this final operation was, given the vast amount of data generated, to synthesize the predictions of each GCM, to compare their responses and eventually to classify them accordingly. GCMs will be selected for subsequent research on the basis of this classification.

2.5.7. File name coding
Given the constraints imposed by ArcGIS on the number of character for grid names (13), even such trivial matter as file naming required an informative and consistent coding system. We used the following twelve characters for file naming:

- The first two digits, from 01 to 23, referred to the GCM used;
- Characters 3 and 4 (A1, A2, B1) referred to the respective GHG scenarios;
- Characters 5 and 6 (25, 55, 85) referred to the midpoints of the future time horizons (2010-2039, 2040-2069, and 2070-2099);
- Characters 7 and 8 (pr, ta, th, tl) referred to the variables: precipitation (pr), average temperature (ta), maximum temperature (th) and minimum temperature (tl);
- Characters 9 and 10 (ch, rs, ds) referred to the type of map: coarse climate change map (ch), resampled change map (rs), final downscaled map (ds).
- Characters 11 and 12 referred to the months of the year (01 to 12)

3. Results

Using the methods and processing steps outlined above, the following grid maps were generated:

Resampled change maps (5184 maps)
- 7 GCMs x 4 variables x 3 scenarios x 3 time horizons x 12 months (= 3024)
- 10 GCMs x 2 variables x 3 scenarios x 3 time horizons x 12 months (= 2160)
- Unit: °C for temperatures, dimensionless for precipitation (ratio)
- Extent: rectangle 32° to 58°N, 44° to 98.5°E

Future climate maps (5184 maps)
- 7 GCMs x 4 variables x 3 scenarios x 3 time horizons x 12 months (= 3024)
- 10 GCMs x 2 variables x 3 scenarios x 3 time horizons x 12 months (= 2160)
- Unit: °C for temperatures, mm for precipitation
- Extent: Central Asian countries plus the Chinese province of Xinjiang.

Averaged change maps (918 maps)
- Yearly: 17 GCMs x 2 variables x 3 scenarios x 3 time horizons (= 306)
- Summer and winter: 17 GCMs x 2 variables x 3 scenarios x 3 time horizons (= 612)
- Unit: °C for temperatures, dimensionless for precipitation (ratio)
- Extent: rectangle 32° to 58°N, 44° to 98.5°E

As mentioned earlier, the averaged change maps were produced in order to classify the different GCMs according to the magnitude and the patterns of the changes in temperature and in precipitation.

Differences between GCM responses are logically expected to be the most marked under the scenario A2, with the most pessimistic GHG emission trend. Annual averages of precipitation and mean temperature change for the third time horizon (2070-2100) under this scenario are visualized in respectively Figure 2 and Figure 3.

As for the precipitation change, GCMs generally predict a reduction in the west of the study area, as an extension of the precipitation decrease in the Mediterranean basin, and a slight increase in the East. Some GCMs (GFDL-CM2.0 and 2.1, IPSL-CM4, ECHO-G, UKMO-HadCM3 and GISS-ER) predict this reduction to happen in about half of the study area, with a more or less pronounced decrease over Turkmenistan, where precipitation is already very low. On the other hand GCM CCSM3 shows a completely opposite trend of increasing precipitation over the entire study area. Others (BCCR-BCM2, CSIRO-MK3, MIROC3.2, CGCM3.1 T47 and T63, CNRM-CM3, and even INM-CM3.0) predict a relative status quo in most of the study area with a significant increase in the Xinjiang province, although in absolute terms the change is relatively small.

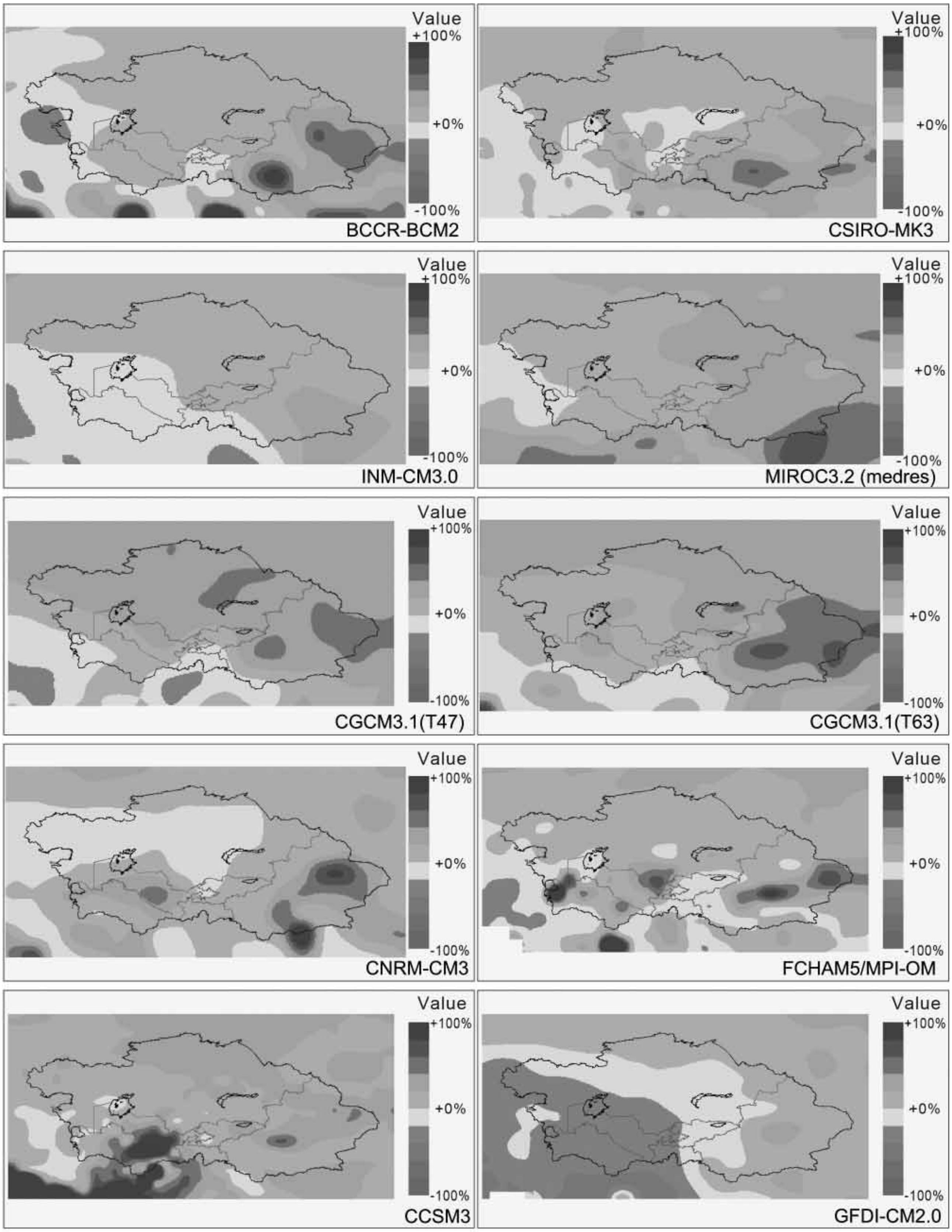
Concerning the temperature change, all GCMs agree on a significant warming (roughly from +2°C to +5°C) over the whole area, with for most of them predicting a slighter temperature increase in the west, around the Caspian Sea. MIROC3.2, ISPL-CM4, UKMO-HadCM3 and ECHO-G predict a more intense warming towards the North, reaching tremendous levels of +7, +8°C. On the other hand, PCM and MRI-CGCM2.3.2 show a relatively limited increase (+2°C to +4°C) of temperature with very little spatial variations.

4. Conclusions

A key challenge faced in generating basic maps for climate change research is the proliferation of data layers resulting from the combination of climatic variables, GHG emission scenarios, time horizons of interest, and GCM model outputs. Processing all needed variables for all ‘possible futures of interest’ within a feasible time frame requires a level of automation comparable to an industrial process.

The generated high-resolution climate change maps take up a huge storage space, in our study of the order of two terabytes. Whereas a consistent filing system can help in accessing all this information, it will be preferable in the future to reduce the storage needs. This could be achieved, for example by retaining in the database only the coarse-resolution input GCM data, eventually transformed into a compatible GIS format, and generating the high-resolution maps on the fly using automation programs embedded in the GIS software.

The results demonstrate once again the huge discrepancy between model results, especially in precipitation. However, our downscaled data from Central Asia and NW China show also for temperature a large variability in model output. For regional planning these differences may be less important, but for local level adaptation it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MIROC3.2 (medres)
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CGCM3.1(T47)
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CGCM3.1(T63)
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CNRM-CM3
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GFDI-CM2.0

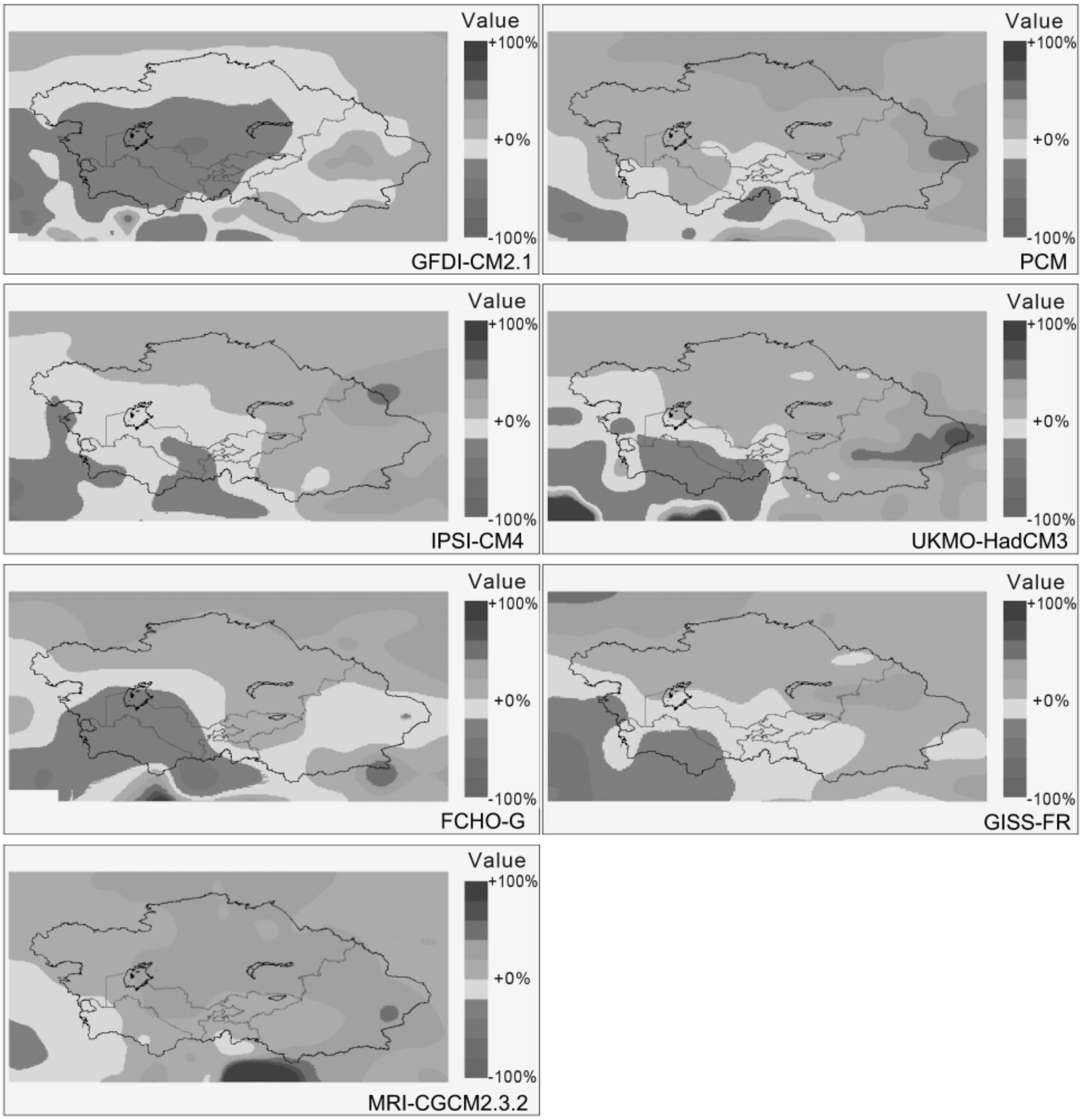
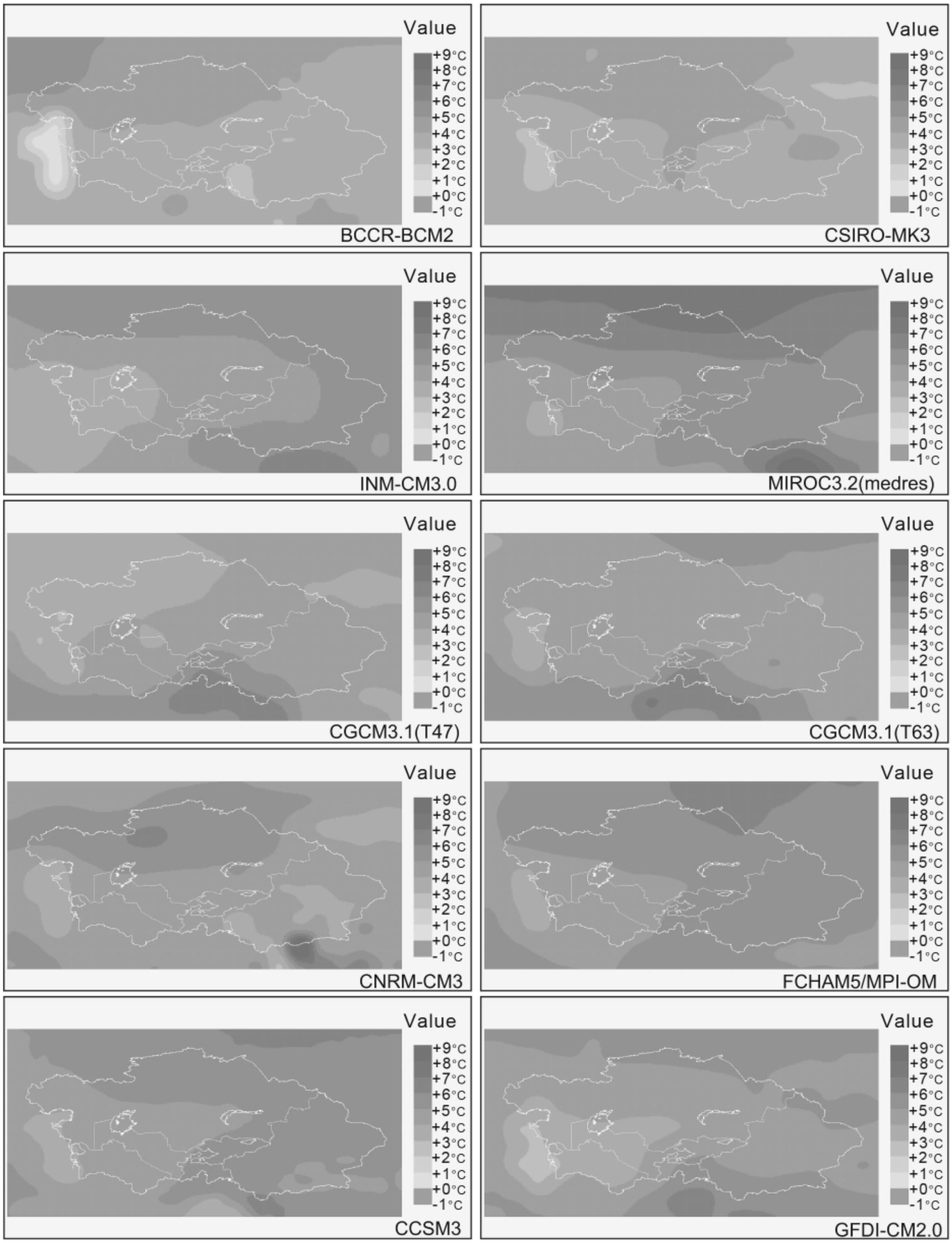


Figure 2. Comparison between 17 GCM models of average annual change (%) in precipitation for the A2 scenario in 2070-2100.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+9°C
+8°C
+7°C
+6°C
+5°C
+4°C
+3°C
+2°C
+1°C
+0°C
-1°C
BCCR-BCM2
CSIRO-MK3
INM-CM3.0
MIROC3.2(medres)
CGCM3.1(T47)
CGCM3.1(T63)
CNRM-CM3
FCHAM5/MPI-OM
CCSM3
GFDI-CM2.0

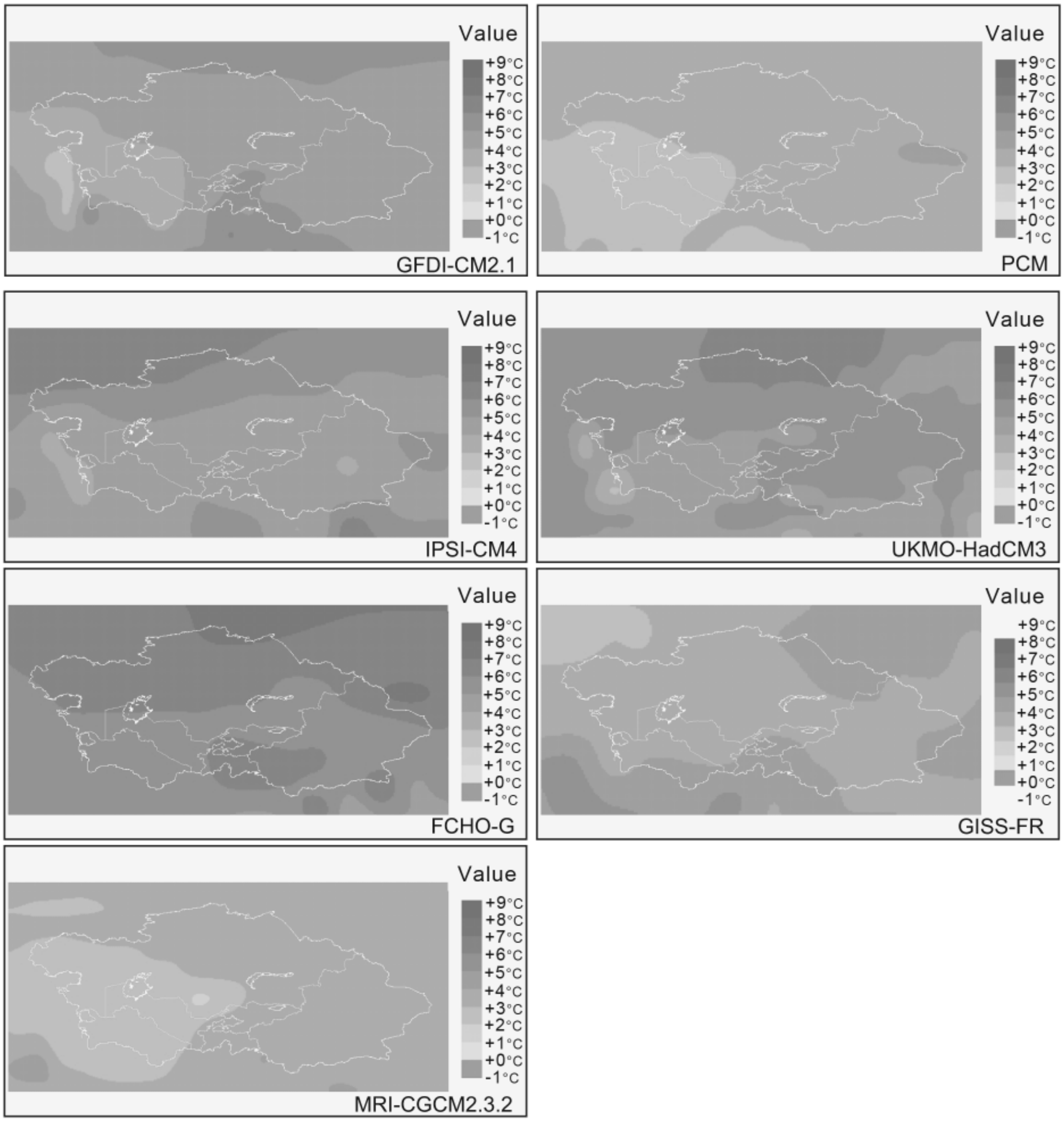

Figure 3. Comparison between 17 GCM models of average annual change (°C) in temperature for the A2 scenario in 2070-2100.

certainly makes a big difference whether the expectation of an average temperature increase is for 1-2°C or for 7-8°C.

The variability in predictions of change between different models is certainly not new and has been recognized by the IPCC. Especially in mountain areas, which in Central Asia occupy a pivotal role in water resource availability, the reliability of precipitation change projections depends critically on the ability of a particular GCM to model weather-terrain interactions. Indeed the IPCC Working Group 1 Report goes as far as stating that *"projections of changes in precipitation patterns in mountains are unreliable in most GCMs because the controls of topography on precipitation are not adequately represented"* (IPCC 2007, p.886 Box 11.3).

Most GCMs operate on a smoothed topography and strongly underestimate the effects of high altitudes. Some of them include corrections such as the gravity-wave drag to take into account the influence of sub-grid scale orographic features, but overcompensation may distort the simulations as well. For these reasons, it remains prudent practice not to rely on the output of a single model, but, as was the case with the IPCC's 2080/2099 projections, to average the results from different GCMs.

Building on this first line database of high-resolution climate change maps, the next step towards the goals of the ICARDA-ADB project will be to make a selection of the most appropriate GCMs. Key criteria for selection will be GCM resolution, the modeling of atmospheric processes over mountains, and their similarities in response to forcing (as presented earlier for year averages). Additional criteria can include responses averaged over seasons, or, better, correlations between observations and GCM simulations for 1961 and 1990.

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Trend analysis for rainfall and temperatures at three locations in Jordan

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Abstract

One of the major challenges that face global agriculture is climate change and shortage of water. The impact of climate change combined with the water shortage will adversely affect agriculture in the Jordan. Agriculture in Jordan was one of the important sectors of the national economy during 1960s. During the last 20 years, the status has declined due to many factors; among these are drought occurrence and poor rainy seasons. A linear trend analysis (series data) for rainfall and mean maximum temperatures in three locations in Jordan (Irbid, Amman and Raba) was applied using a base line for 30 years (1976 to 2005) to forecast and project rainfall and maximum temperatures for 20 years (2006 to 2025). Rainfall trend showed a decrease at the rate of 1.8, 1.4 and 1.6 mm/year in Irbid, Amman and Raba, respectively. On the other hand, mean maximum temperatures showed an increase by about 0.04 ºC/ year. The present study showed the danger and adverse impact of the climate change on the crop production in Jordan. Consequently, new measures and agricultural practices should be taken to cope with these climate changes.

Keywords: leinear trend analysis, rainfall, temperature, climate change.

1. Introduction

Some of the most deep and direct impacts of climate change over the next years will be on agriculture and food systems. Results and quantitative assessments show that climate change will adversely affect food security and the small farmers in poor countries will likely be those most affected (Brown and Funk 2008; Schmidhuber and Tubiello 2007). The food price crisis of 2008 has led to the re-emergence of debates about global food security and its impact for achieving the first Millennium Development Goal (MDG) regarding poverty and hunger. The United Nations Development Programme (UNDP) warns that the progress in human development achieved over the last decade may be slowed down or even reversed by climate change, as new threats emerge to water and food security, agricultural production and access, and nutrition and health. By 2080, the impacts of climate change on droughts, heat waves, floods and rainfall variation could make another 600 million people face malnutrition and increase the number of people facing water scarcity by 1.8 billion (UNDP 2008).

The Intergovernmental Panel on Climate Change (IPCC 2007) reports that global mean surface temperature is projected to increase in a range from 1.8 ºC to 4.0 ºC by 2100. Therefore, in drier areas, all climate models predict increased evapotranspiration and lower soil moisture levels as well as increase in drought and heat waves, especially in the Mediterranean region (IPCC 2001, 2007).

Various studies have been conducted in different parts of the world for detecting climate trends and changes. Some of these have shown significant trends (Capodici et al. 2008; Gemmer et al. 2004; Feidas et al. 2007). However, very limited work has been conducted at the national level especially on time series analysis. Thus, the general aim of this study is to detect the presence of significant trends in total rainfall and maximum temperatures in three ecological zones in Jordan.

2. Materials and methods

Data on total rainfall and mean maximum temperatures for the three different regions (Irbid, Amman and Raba) of Jordan were obtained from the Jordanian Meteorological Department.

Time series data on total rainfall and maximum temperatures since 1976 till 2005 (base line) were analyzed and forecasting done till 2025 using trend analysis. Trend analysis is a tool used to fit a general trend model to time series data and provide forecasts. The trend analysis for a time series data can take different forms such as linear quadratic, or cubic. In our analysis we used the linear, trend model. In this case, a standard regression model is used to describe the relationship between the rainfall and the time:

$Z_t = \alpha + \beta t + a_t$,where Z_t is amount of the rainfall at time t , β is the rate of change of rainfall over the time, α is the amount of the rainfall at time zero, and a_t is a random error. The best fit line of the above model is given by the equation $\hat{Z}_t = \hat{\alpha} + \hat{\beta} t$ where $\hat{\alpha}$ and $\hat{\beta}$ are the estimated values α of and β , respectively. The above model was used to forecast the future values of $\hat{Z}_t$. Similarly, the same procedure was applied to forecast the trends in temperature (Wei 2006).

3. Results and discussion

3.1 Prediction of rainfall

Minitab Software was used to determine rainfall trend for the period of 1976 to 2005 (base line) using linear trend analysis. The total rainfall differed from location to location (Table 1). Total rainfall was 468, 258, and 341mm in Irbid, Amman, and Raba, respectively. Trend analysis for rainfall in Irbid, Amman and Raba are shown at Figure 1, 2 and 3, respectively. The analysis showed a negative trend in total rainfall in all the locations. The decrease in rainfall was 1.8, 1.4 and 1.6 mm/ year in Irbid, Amman and Raba, respectively.

3.2 Prediction of mean maximum temperatures

The procedure used for trend analysis for rainfall was also applied for analysis of trend in maximum temperatures. Mean maximum

Table 1. Maximum, minimum and mean values for rainfall (mm) in Irbid, Amman and Raba

	Locations		
	Irbid	**Amman**	**Raba**
Maximum	877	450	638
Minimum	214	98	123
Mean	468	258	341

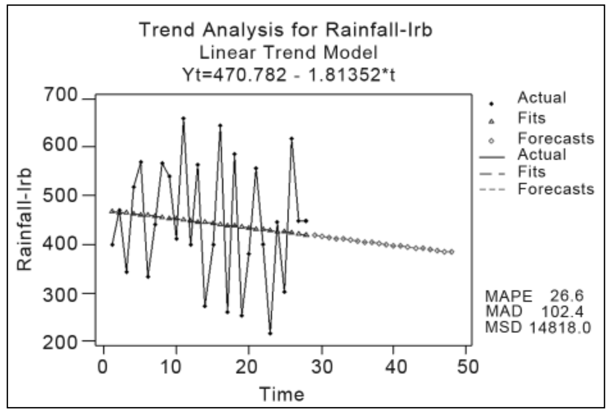

Figure 1. Rainfall (mm) trend from 1976 to 2005 and its forecast till 2025 at Irbid.

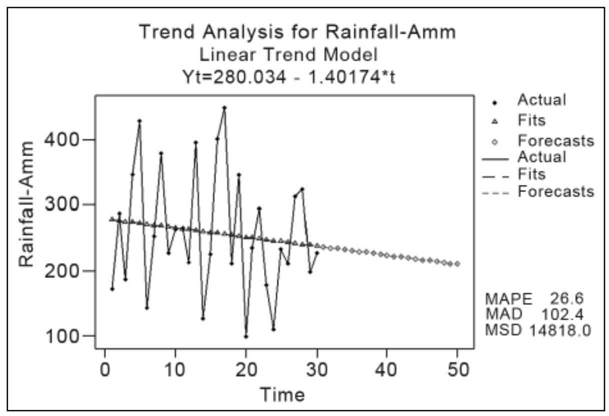

Figure 2. Rainfall (mm) trend from 1976 to 2005 and its forecast till 2025 at Amman.

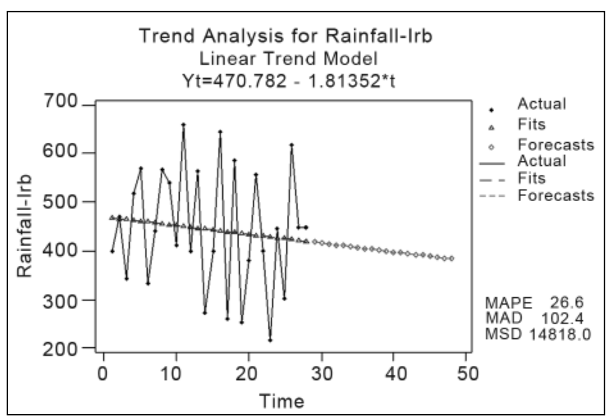

Figure 3. Rainfall trend from 1976 to 2005 and its forecast till 2025 at Raba.

temperature was 23.0, 23, 2 and 22.1ºC in Irbid, Amman, and Raba, respectively (Table 2). Trend analysis for temperatures in Irbid, Amman and Raba are shown at Figure 4, 5 and 6, respectively. The trend in maximum temperatures was positive. The increase in mean maximum temperatures was 0.04, 0.03 and 0.08 ºC in Irbid, Amman, and Raba, respectively.

Table 2. Maximum, minimum and mean values for temperature (ºC) in Irbid, Amman and Raba.

	Locations		
	Irbid	**Amman**	**Raba**
Maximum	24.4	24.4	23.8
Minimum	21.2	21.4	20.4
Mean	23.0	23.2	22.1

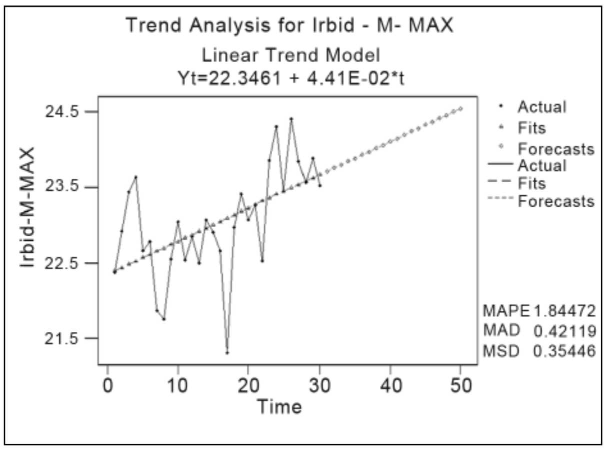

Figure 4. Maximum temperature trend since 1976 to 2005 and forecast to 2025 at Irbid.

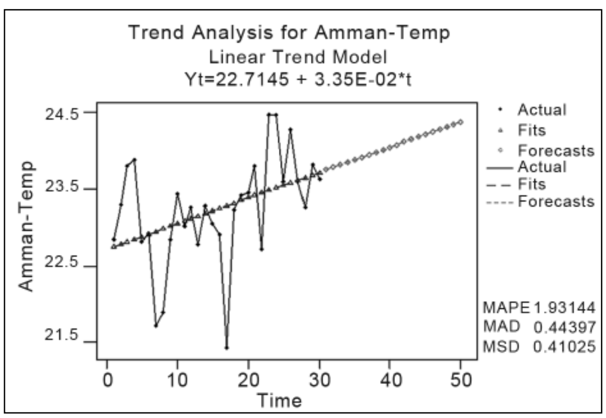

Figure 5. Maximum temperature trend since 1976 to 2005 and forecast to 2025 at Amman.

Based on the above results, it is evident that Jordan will witness a decrease in total seasonal rainfall and an increase in temperatures. These results are in agreement with those obtained by other workers (Capodici et al. 2008; Feidas et al. 2007; Gemmer et al.,2004) and with predictions in the IPCC reports.

4. Conclusions

The aim of this study was to detect the presence of significant trend in the time series of climatic variables (total seasonal rainfall and mean maximum temperatures) to forecast these variables in the future. Linear trend analysis was efficient for prediction and forecasting. The analysis showed a negative trend in total rainfall and positive trend in mean maximum temperatures. Thus, new measures and agricultural practices should be taken to cope with the adverse effects of these climatic changes.

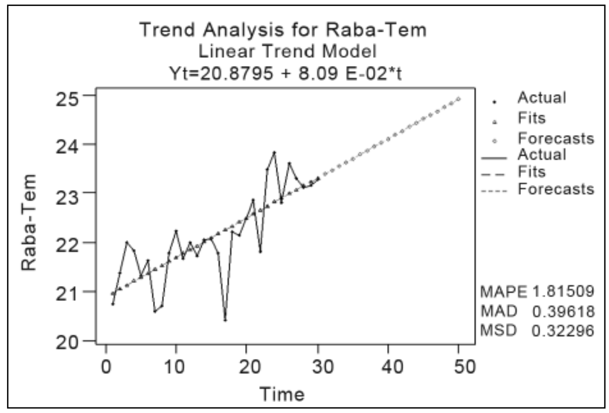

Figure 6. Maximum temperature trend since 1976 to 2005 and forecast to 2025 at Raba.

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Monitoring vegetation characteristics and dynamics as a response to climatic variability in the Eastern Mediterranean regions of Jordan using long-term NDVI images

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Abstract

Climatic variability and drought periods affect the pattern of vegetation growth and agriculture production particularly in the dryland regions. This research addresses long-term variation in vegetation cover as a response to climatic variability in Jordan in the time period from 1989 to 2004. Long term NDVI and rainfall records time series analysis was combined to detect the tendencies of vegetation dynamics and phenological characteristics. The analysis is based on monthly one km MEDOKADS NDVI data. Analyses of the magnitude and phase spectra of the NDVI are able to characterize the vegetation conditions and plant growth cycle. Results of the seasonal cyclic components of vegetation patterns are very useful in distinguishing the type and extent of the ecological zones in Jordan. The changes in vegetation dynamics were highly related to the rainfall amounts and distribution. The 16-year average seasonal cycle of NDVI provides a clear distinction between the major vegetation types. The best distinction between the time profiles can be made within the months from January to March along the different ecological zones. The rainfall amounts and NDVI values are highly related and have a stepwise trend pattern with 4-5 years interval.

Keywords: climatic variability, Jordan, NDVI, phase cycle, time series.

1. Introduction

Dryland ecosystems are characterized by high spatial and temporal variability mainly due to the pattern of rainfall and scarcity of water resources. The vegetation and land use in these systems are the main source of food and forage production (Backhaus et al. 1989; Ray 1995). Management of natural vegetation requires an efficient system for monitoring its annual and seasonal conditions and characteristics, which can be implemented by remote sensing techniques.

The possibility of assessing natural vegetation phenology and conditions using satellite imagery has been long investigated (Townshend and Justice 1986; Kowabata et al. 2001; Tateishi and Ebata 2004; Xiao and Moody 2004). The phenological characteristics of land cover and vegetation species can be differentiated from each other by studying their spectral and temporal signatures (Tucker et al. 1985). Therefore, high temporal resolution of NOAA satellite imagery has been used for this purpose (Al-Bakri and Suleiman 2004).

Previous studies have shown the advantage of using the AVHRR data for monitoring the vegetation condition compared to other methods that relay on climate measurements (Hutchinson 1991; Lambin et al. 1993; Kogan 1997; Budde et al. 2004; Evans and Geerken 2004). In this context, many studies for phenological monitoring have been implemented based on the high-temporal approaches at global scale, especially using high frequency NOAA (AVHRR) data (Tucker et al. 1984; Justice et al. 1985; Propastin et al. 2007; Tao et al. 2008). Vegetation phenology in dryland regions is largely influenced by inter-annual climatic changes such as in temperature and precipitation, which profoundly influence plant phenological status such as the date of onset of green-up, the rate of biomass accumulation, and the rate of vegetation senescence (Wang et al. 2001; Lee et al. 2002).

The main objectives of this research were to (i) investigate the annual vegetation growth cycle in different agro-ecosystems in Jordan using time series analysis in the period from 1989 to 2004, and (ii) analyze the long term trend of vegetation conditions and characteristics.

2. Environmental conditions

Jordan is located in the eastern Mediterranean region between 29°11´ and 33°22´ N latitudes, and between 34°19´ and 39°18´ E longitudes.

2.1. Climate

Typical of the Mediterranean climate, the rainfall in Jordan is concentrated in the cool winter season while it is dry and hot during the summer. The rainy months extend from October to May, with rain being heaviest between December and March. The rainfall shows high level of annual and seasonal variability and it decreases from North to South and from West to East. Average rainfall ranges from 600 mm/year in the north to less than 50 mm/year in the south and in the east. More than 90 % of the country's area is included in the arid zone and receives less than 200 mm annual rainfall.

2.2. Land use and natural vegetation

Vegetation cover in Jordan has been divided into broad regions according to the climate and the geomorphology. The natural vegetation classes are natural forest, Mediterranean vegetation, steppe vegetation, grasses and desert plants.

The Mediterranean vegetation region contains the major areas of natural and semi-natural woodlands, and it is dominated by natural pine and evergreen oak forests (Tillawi 1989). The steppe vegetation region occurs mainly in the 200-350 mm rainfall zone in association with Mediterranean transition species. Two major types of steppe vegetation can be recognised: the Artemesia brush steppe and grassland steppe. The grasses and desert plants are dominant under low rainfall zones and arid conditions. On the other hand, the main agricultural land use is classified into tree crops, annual field crops, irrigated farms and rangeland. The rangelands have the largest area and are dominant mainly under low rainfall conditions in the eastern and southern parts of Jordan.

2.3. Soils

The main soil types in Jordan according to the USDA soil Taxonomy are Xerochrepts, Chromoxererts, Aridisols and Entisols (MOA 1995). The Xerochrepts and Chromoxererts soils developed under xeric moisture regime, and are found on upper, lower and flat slopes in the mountainous and northern parts of Jordan. However, the dominant soils in Jordan are Aridisols and Entisols, which developed under aridic moisture regime and cover most in east area and south area desert parts. Aridisols cover more than 60% of the country.

3. Materials and methods

3.1. Precipitation data

The climate data used in this study consist of monthly rainfall collected by the national department of meteorology for 12 representative stations from 1989 to 2004 (DOM 2005). The records were averaged to mean monthly values, corresponding to the monthly periods of the NDVI data.

3.2. Image data and analysis

The NDVI data were derived from the "Mediterranean Extended Daily One Km AVHRR Data Set" (MEDOKADS) (Koslowsky 1998; Han and Kamber 2001). All time-series calculations were carried out using the TimeStats software package (Hand et al. 2001; Udelhoven et al. 2009).

Two non-parametric trend tests were used. This study in the significance of long-term variations was assessed by the Modified Seasonal Mann-Kendall (MSK) test which is suited for monotonic trend detection independent from its functional type (e.g. linear, quadratic) (Schlittgen and Streitberg 2001; Piwowar and LeDrew 2002). The Seasonal Kendall (SK) slope estimator represents a non-parametric alternative for the slope co-efficient in a linear trend analysis and is applied to describe the magnitude and inclination of a trend (Box and Jenkins 1976).

3.3. Time series parameters

TimeStats software offers tools to describe cyclic components in a time series. Methods applied in this study include the magnitude and phase spectra from NDVI series and the cyclic components of the annual and semi-annual vegetation growth cycle. The magnitude measures the maximum variability of the record in a specific period of time, whereas the phase indicates the point in time when the maximum value occurs in the related period. The cyclic components feature imbedded in the TimeState software is able to detect the annual, seasonal and inter-seasonal vegetation growing season. The power spectrum is widely used to describe the vegetation growth cycle (Andres et al. 1994), and bears information about land-cover conditions and different vegetation classes, which can be linked to physical and temporal parameters for better understanding of vegetation-environment interactions (Azzali and Menenti 1999). The power spectrum of the NDVI signal is particularly useful to compare the strength of the annual growth cycles of various vegetation types or to interpret inter-annual curves. Amplitude and phase values at different frequencies measure the relative weights of different periodic climatic processes.

In monthly series, NDVI amplitude and phase values for period of twelve and six months are closely related to agro-biological phenomena, such as the growth of vegetation in response to the seasonal pattern of rainfall and temperatures (Azzali and Menenti 2000). The magnitude and phase term of the annual NDVI and semi-annual cycle was calculated separately for each year from MEDOKADS data.

4. Results and discussion - vegetation conditions

4.1. Spatial distribution of NDVI and climatic factors in the study area

There are two factors influencing the spatial patterns of vegetation and climatic variables in the study area: the climate gradients of north-south and west-east directions and the altitude gradient. Generally, the spatial variance of NDVI and climatic variables are strongly predicted by a rainfall direction factor, but the relief conditions slightly deform this rule and make the spatial patterns more difficult.

Distribution of vegetation and rainfall variables display similar spatial patterns, thus the NDVI distribution pattern is in accordance with average value of rainfall amounts and distribution. Average precipitation decreased markedly from the northern to southern highlands; from about 600 mm in the northern part to less than 300 in the southern part.

Also the precipitation increased from about 50 mm in the desert zones to about 200 mm in the transitional steppe zone. This relationship can be explained by analysing the mean NDVI and magnitude of the annual vegetation growth cycle. The 16-year average of NDVI ranges from less than 0.05 in the southern and eastern desert area to about 0.40 in the northern highland zone.

The highest mean annual NDVI values ranged between 0.20 and 0.39 and were found in the highland areas extending from the northern to the southern mountains. This area receives the highest rainfall in the country and it is covered mainly by natural forest and fruit trees. NDVI values mostly greater than 0.25 were recorded in the northern part of the highland regions, under high rainfall.

NDVI values in the transitional vegetation zone ranged between 0.12 and 0.20. On the other hand, the eastern and southern desert parts of the country had the minimum mean NDVI values, less than 0.1. The largest parts of this class are covered by rangeland and desert grasses. Values lower than 0.05 indicate areas with no photosynthetic activity; these are mainly non-vegetated desert surfaces of bare soil and rock.

4.2. Vegetation growth cycle

Figure 1 shows the spatial pattern of the semi-annual vegetation phase cycle, which is corresponding to the seasonal vegetation growth cycle, derived from the monthly NDVI during 1989 to 2004.

The annual phase analysis indicated three major phases of vegetation cycles, appearing in February, March and April. The maximum NDVI phase cycle occurred in April, and was distributed along the northern and western mountains regions. The area is dominated by high altitude and covered by forest and perennial vegetation. The most dominant phase cycle occurred in March, which represents the effect of rainfall distribution and climatic conditions on different agricultural land use activities. In contrast, the maximum NDVI in the north-eastern and southern parts occurred early, in February. This is due to the effect of early rainfall events and high temperatures. Presence of irrigated farms, especially in the eastern and northern parts of Jordan might have also contributed to this.

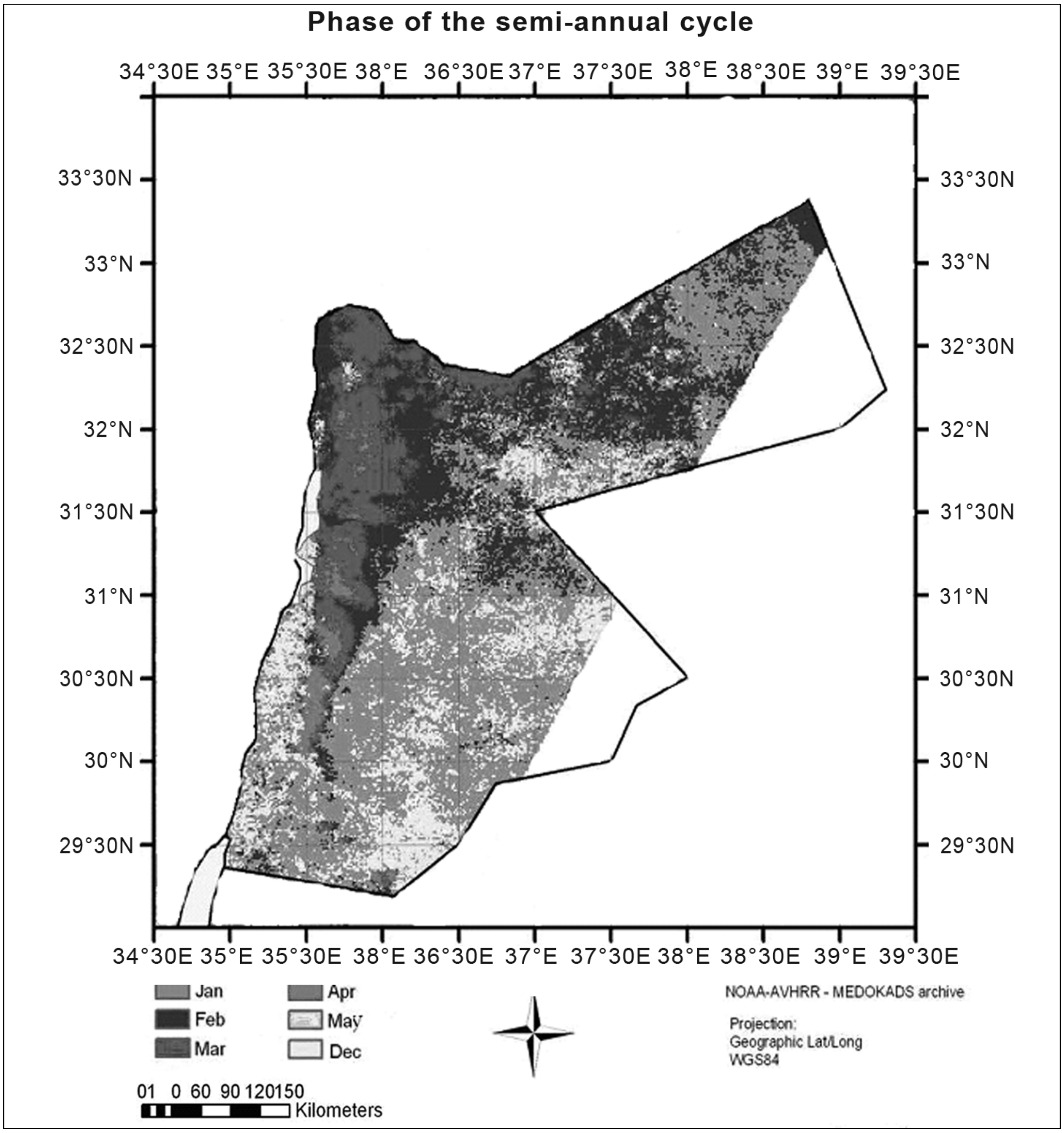

Figure 1. Phase of the semi-annual vegetation growth cycle in Jordan derived from the monthly MEDOKADS NDVI time series during the time periods from 1989 to 2004.

Table 1. Distribution of average NDVI and appearance of phase cycle in each ecological zone in Jordan based on long term monthly NDVI during the time period from 1989-2004

Semi-annual phase cycle	Average NDVI	Dominant ecological zone
May	0.3-0.39	Northern Highland-high altitude
April	0.25-0.33	Southern Highland-high altitude
March	0.15-0.25	Highland-lower altitude
February	0.1-0.2	Transitional vegetation zone and irrigated farms
January	0.05-0.10	Desert Area- Arid lands
December	0-0.05	Desert Area – Arid lands

However, analysis of the semi-annual seasonal cycles gives more precise and clear distinction of the phase magnitude for different ecological zones. It showed six distinct seasonal cycles, in December, January, February, March, April and May. The characteristics of the major types of vegetation zones are strongly distinguished by NDVI values and seasonal phase cycles of the growing season as given in Table 1.

The northern highland region recorded the highest average NDVI values (0.30-0.39) in May growing phase, followed by southern highlands (0.25-0.33) in April. Most of the growing phase cycle of the land use types in the highland areas appeared in March (NDVI values 0.15-0.25). The growing seasons of the transitional vegetation zone and irrigated farms in the desert area appeared to be in February and had NDVI values of 0.10-0.20. The desert vegetation zone displayed the lowest NDVI values, in January and December with NDVI value of 0.05-0.10 and 0.0-0.05 respectively.

The May and April phase corresponded to the permanent land use and natural vegetation types under high altitudes highland regions. The March phase reflected the fruit trees and annual crops growth cycle under high rainfall conditions, but with lower altitude than the April and May phases. The February phase was dominant in the steppe transitional zone and in the irrigated areas in the eastern parts. However, most of the southern and eastern parts of the country were dominated by January and December phases and they had the lowest NDVI values and rainfall amounts.

The spatial distributions of the seasonal growing phase derived from NDVI series corresponded to the delineation of agro-ecological zones, as defined by climate, geomorphology and land use. The strong variations visible in the individual seasonal NDVI phases are mainly attributed to within annual and inter-annual rainfall patterns. In addition, there are other non-climatic factors such as soil moisture content, soil temperature and site characteristics that also have their effect.

4.3. Temporal behaviour of vegetation within the growing season

Figure 2 illustrates within-seasonal growth cycles of NDVI from 1989 to 2004 compared with the seasonal precipitation for the same period over the different agro-ecological zones based on long term monthly data. The 16-year average (1989-2004) of monthly NDVI values increased rapidly during early November-December, peaked during January-February, decreased during March-April, and reached a constant value during June-August.

Precipitation showed one peak, increasing from late October to November and peaking in late December and January. After that there was a slight decrease till the end of March. Minimum precipitation occurred in April and May. In the summer months, June to September, the precipitation was nearly zero. The growing season is approximately from October to May. The growth of vegetation begins early January and peaks in February, depending on the ecological zone and the climatic conditions.

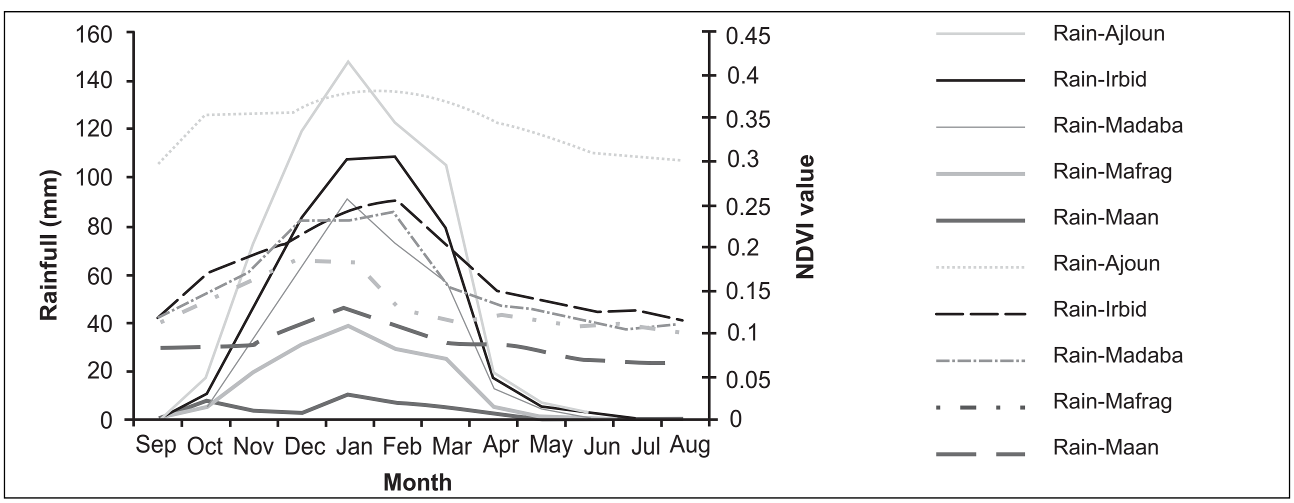

Figure 2. Seasonal pattern of NDVI and rainfall amounts for different ecological zones in Jordan based on long term monthly data for the period 1989 to 2004.

All annual vegetation types had minimum NDVI values (almost zero) at the beginning of the growing season, in October and November, while the permanent and natural vegetation types had minimum NDVI values in the late summer and at the beginning of the growing season. Generally, all vegetation types displayed increases in NDVI from December to February, followed by consistent decrease in June-August. Also, the 16-year average NDVI time series of the vegetation types at different ecological zones showed uniform behavior through the growing season but with different NDVI values.

The vegetation of the highland zone reached the maximum value between March and April depending on the rainfall and temperature regimes of the year. After that, the values decreased consistently during the summer and autumn months, reaching their minimum at the end of August and September. The areas under tree crops showed their maximum NDVI value generally in mid March. The NDVI values showed high variability in this class due to wide differences in tree types, age and phenological cycle. The NDVI values remained high until April, after which they decreased slowly until the end of the growing season.

The steppe and transitional vegetation zone had the highest values during the spring months of January-March. The separation in NDVI values began in early February. Desert vegetation begins its development earlier in the growing season in December and January.

In conclusion, average seasonal cycle of NDVI provides a clear distinction between the major vegetation types. The best distinction between the time profiles can be made within the spring months, from December to March, when the vegetation types display quite different and clear distinguishable attributes of their canopy such as leaf area, percent coverage, and biomass. These differences reflect in clear differences in the monthly NDVI time-series, over different ecological zones.

4.4. Relationships between NDVI and precipitation pattern

For natural vegetation and rainfed agriculture, precipitation is usually a major source for soil moisture, which is critical for plants survival and productivity. Change in NDVI of native vegetation during the growing season can be affected by the amount and timing of rainfall (Schultz and Halpert 1995). The previous studies have also shown presence of a time lag of one month between a weather event, especially rainfall, and the vegetation response to it (Richard and Poccard 1998; Yang et al. 1998; Li et al. 2002). Therefore, while analyzing NDVI-precipitation relationship for individual agro-climatic zones, the correlation coefficients have been calculated imposing different time lags from 0 to 3 months.

For the entire study area, correlations, calculated with time lags of 0 to 3 months imposed on the NDVI data, have been significant and strong. The highest correlation coefficient was achieved by imposing a time lag of one month in the highland regions, and no time lag in the desert and transitional zone. About 35 % of all variation in NDVI was explained by variation in rainfall. This shows a high dependence of vegetation growth on rainfall but a large amount of NDVI variance remained unexplained, attributable probably to other factors of climatic and non-climatic nature such as air and soil temperature, evaporation, parent rocks, soil type or vegetation type (Yang et al. 1997). Another problem is that a spatial average over the entire study region gives a good general impression of the relationship between vegetation activity and precipitation, but it screens out response of individual vegetation types and vegetation communities to the climatic factor being investigated.

The strength of the NDVI-precipitation relationship gradually increased from desert grasses under low rainfall, to reach the highest value for steppe vegetation, annual field crops and fruit trees under medium rainfall amounts, and then decreased again under permanent vegetation under high rainfall. The correlation coefficients were 0.25 under desert area and low rainfall zone, 0.31 under highland and high rainfall zone, and 0.45 under highland and medium rainfall zone.

The results of this analysis are in agreement with those obtained by others for dry regions (Richard and Poccard 1998; Wang et al. 2003; Propastin et al. 2007). The degree of this effect depends on the rainfall and the land use system. For instance, the effect is very obvious in the middle and southern parts of highland, which is characterized by rainfall amounts between 300-450 mm/year.

The NDVI value of vegetation types under this rainfall regime is more sensitive to the rainfall variability than the higher rainfall and low rainfall regimes such as the northern highlands, and desert area respectively. Generally, the correlations are weaker with a decrease in abundance and with saturated abundance of vegetation cover.

The analysis of the seasonal rainfall time series variations with the corresponding NDVI values in the period from 1989 to 2004 showed a stepwise trend. The strong variations visible in the individual annual NDVI phases are mainly attributed to the within the year and inter-annual rainfall patterns. Figures 3 show the dynamics of short lived trends that represent monthly NDVI and rainfall pattern.

Also the NDVI differences from a windowed trend analysis have been generated using a moving window of 60 months with 48 months overlapping between two neighboring periods. A high dynamic of the NDVI becomes visible: the period 1989-1996 was dominated by negative trends, while in the following years until 2000 a reversal in trend occurred for most parts of the country. After the year 2000, the trend became negative again and in the last period (2000-2004) there was a distinct trend reversal. Obviously, the short-term behaviour in the NDVI is driven by varying climatic conditions and by changing atmospheric attenuation.

The decrease in NDVI between 1989 and 1994 can be attributed to the Aerosol effect in 1991, which contributed to non-uniformity of time series. From 1991 till 1995 the trend, however, was additionally influenced by the dry year of 1995, which caused NDVI values to decline. A clear climatic effect is the decline in the NDVI at the end of the observation period. In 1999 there was a severe drought and the vegetation did not completely recover in 2000 in spite of better rainfall in that year. This caused the NDVI to decline in the period 1996-2000 and 1997-2001.

5. Conclusion

The main objective of this research was to investigate the long term vegetation conditions and characteristics in Jordan. It also examined within-season interrelations between monthly and

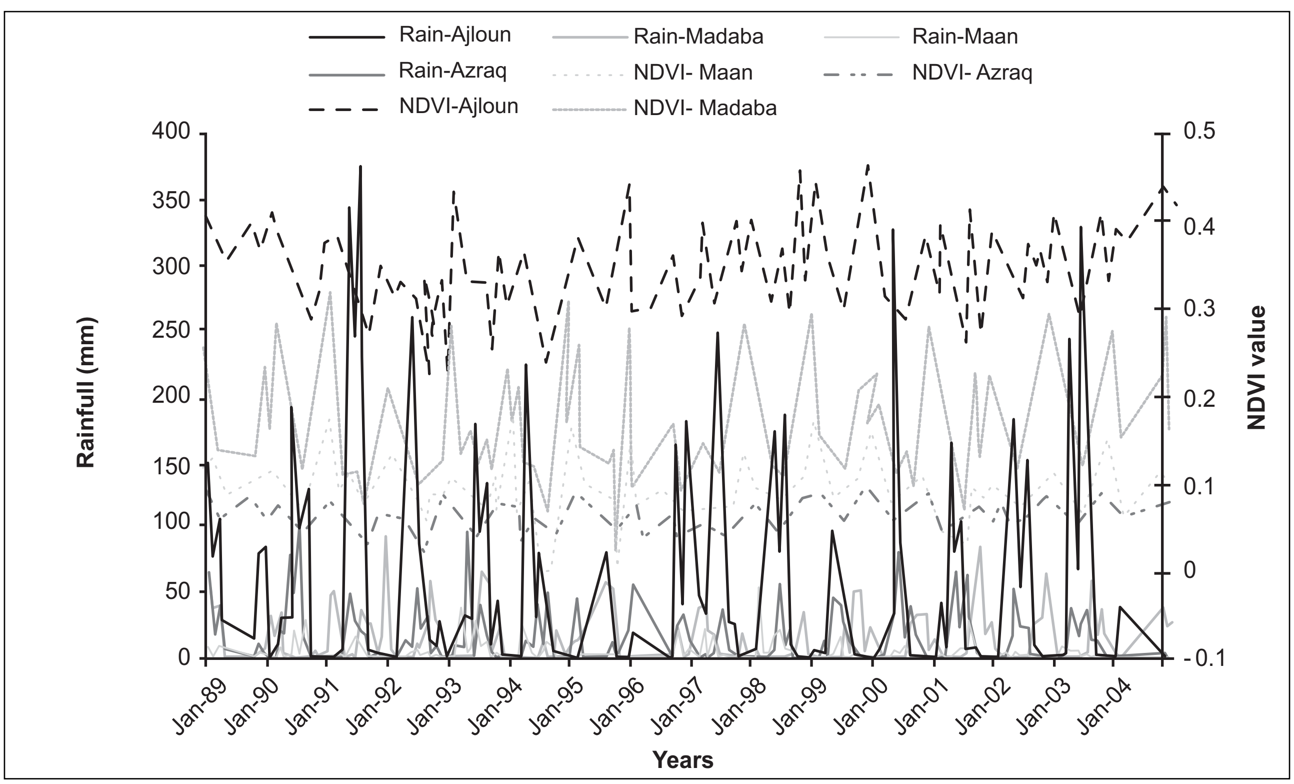

Figure 3. Long term pattern of monthly NDVI and rainfall amounts for different ecological zones in Jordan based on long term monthly data for the period 1989 to 2004.

time-series of MEDOKADS NDVI and analogous series of precipitation variables over the period 1989-2004. Mean monthly and seasonal NDVI clearly reflected differentiation of vegetation cover in the study area, making it possible to stratify the area by vegetation types. The integration of spatial and cyclic analysis of NDVI dataset enabled to (1) extract the temporal signals of vegetation phenology and delineate the ecological zones of Jordan based on the vegetation conditions, (2) determine growing season patterns of vegetation communities and characteristics over different ecological zones, and (3) map the spatial patterns of the relationship between vegetation and rainfall.

The NDVI data revealed substantial sensitivity to the climatic signals, both in time and space, and allowed investigation of the influence of climate variables on the ecosystem. The semi-annual and seasonal cycles confirmed clear distinction of the seasonal phase magnitude of different land use types. Their spatial distribution has been used to determine the actual agro-ecological zones in Jordan based on the current vegetation conditions. These correspond to the delineation of agro-ecological zones, as defined by climate, geomorphology and land use variables. Also, the 16-year average seasonal cycle of NDVI provided a clear distinction between the major vegetation types. The best distinction between the time profiles could be made within the months from January to March. These results illustrated that satellite based vegetation reflectance and analysis of plant cyclic components can serve as a good proxy for characterizing and monitoring the vegetation condition and its variability in drylands ecosystems.

Further analysis has to be performed in order to evaluate correlation between vegetation dynamics and high temporal rainfall and temperature variables (e.g. 10 days interval) over several types of vegetation. The use of soil-based vegetation indices instead of NDVI is also needed. In fact, in areas characterized by sparse vegetation (e.g. desert area), a robust vegetation index should take into account the spectral soil characteristics.

Acknowledgments

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Themes 2 and 3: Impacts of Climate Change on Natural Resource Availability (Especially Water), Agricultural Production Systems and Environmental Degradation, and on Food Security, Livelihoods and Poverty

Land suitability study under current and climate change scenarios in the Karkheh River Basin, Iran

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Abstract

The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) predicts a global increase in mean temperature and a decrease in mean annual rainfall. Such changes will affect not only crops but also land suitability, particularly in the dry areas. Assessing the suitability of an area for crop production requires considerable efforts in terms of information collection that presents both opportunities and limitations to decision-makers. This study used a GIS based method has been used to match the land suitability for winter wheat production based on the biological requirements of the crop and the quality and characteristics of land within the Karkheh River Basin, Iran. Overall suitability is recognized by the most limiting factor method in preference to a weighted GIS model, which scores attributes. The results showed that under current climate condition 8.7%, 7.6% and 28% of the area respectively is 'highly', 'moderately' and 'marginally' suitable for winter wheat production and the remaining (55.7%) is unsuitable. Under climate change scenarios, the suitability of land for winter wheat showed considerable variation. With increased temperature and precipitation, 'highly and moderately suitable' areas increased. With decreased precipitation, 'highly suitable' areas decreased as much as 91%. The methodology could readily be adapted and developed for other soil and climatic conditions.

Keywords: climate change, dry areas, Karkheh River Basin (KRB), land suitability, most limiting factor (MLF) method, winter wheat.

1. Introduction

There is mounting evidence for real global climate change. Global mean temperatures are now about 0.6 ºC higher than 130 years ago, and 1997 and 1998 were the warmest since 1860 (WMO 2000). If present trends continue, the average temperature of the planet will increase by 2.36 ºC by the end of the 21st Century (Mcginty et al. 1997).

This paper describes a climate-soil-site model to assess climate change impacts on land suitability for rainfed winter wheat, focusing on the potential effects of temperature increase and rainfall variables on the land suitability in Karkheh River Basin (KRB), Iran. GIS-based assessments were made for the present-day climate (defined as 1973-1998) and for various scenarios of future climate by 2025 through a Simple Limitation Approach (SLA) (Ghaffari 2000).

2. Material and methods

2.1. Study area

The study area is the Karkheh River Basin (KRB), located in the western part of Iran between 30º 58' to 34º 56' N and 46º 06' to 49º 10' E. The area is about 50,700 km^2 and altitude varies between 3 m above mean sea level (amsl) in Dasht Azadeghan to 3645 m amsl in the Karin Mountains.

2.2. Soil

The original 1:1,000,000 digitized Soil Map of Iran (Banaei 2000) was clipped to the KRB outline. The Soil Map of Iran is a soil association map in which the soil components are classified according to soil taxonomy. Based on the dominant soil type, the soil classes were then regrouped in accordance with their major properties with respect to ‘usability’ into ‘soil management domains’(SMD).

2.3. Topography

Topographical maps were used to select site slopes and altitude information relevant to land suitability. This study used a landform panorama Digital Terrain Model (DTM) of raster format, 10 m resolution, supplied by the Forest, Range and Watershed Management Organization (FRWMO) of Iran.

2.4. Climate

The most important climate characteristics are temperature and rainfall. A database of point climatic data covering monthly averages of precipitation, and minimum and maximum temperatures for the main stations in Iran, covering the period 1973-1998, was made available by the Organization of Meteorology of Iran.

2.5. Climate change scenarios

Several climate change scenarios based on sensitivity tests were selected for use in the study area.

Temperature increase agreed with the analysis of historical climatic data over the last 30 years in the study area. Analysis of rainfall trends did not show such increases, so three options were explored: one consistent with current average rainfall conditions, one 20% less and one 20% more.

The scenarios are summarized below:

Scenario 1 = +20% rainfall,
Scenario 2 = -20% rainfall,
Scenario 3 = +1.5 °C,
Scenario 4 = +1.5 °C and +20% rainfall,
Scenario 5 = +1.5 °C and -20% rainfall.

2.6. Land suitability

The land suitability was expressed in three classes: highly suitable (HS), moderately suitable (MS), and marginally suitable (MG). Moderately suitable and marginally suitable lands were expected to have, with economically feasible inputs, a crop yield of 60-80% and 40-60%, respectively, of that under optimal conditions. Unsuitable (U) land was assumed to have severe production limitations, which could rarely or never be overcome by economic use of inputs or management practices.

2.7. Geographical Information Systems (GIS)

The GIS methodology used in this study identified input data for the land suitability models and developed a modelling procedure for processing and output presentation. Digitized maps, the geographical distributions of soils, topography and agro-climatic regions were captured together with attribute data (e.g. SMD). Overall suitability was recognized by the Simple Limitation Approach (SLA). This method utilizes the concept of “most limiting factor” which corresponds to Liebig’s “Law of the Minimum”.

3. Results

Changes in mean annual precipitation and extreme temperatures were calculated. Temperature increase applied to the year 2050 is assumed to be 1.5 °C more than the current mean temperature. The distribution of mean annual temperatures was based on the 1973-98 record for the study area.

3.1. Slope

Suitability was assessed first in terms of topography. Elevation alone did not affect land suitability since the whole study area was highly or moderately suitable for the crop under consideration. On the other hand, slopes affect land suitability very much. About 22% of the area was marginally suitable with slopes between 8 to 20%; 35% of the study area had very steep slopes (more than 20%), which were unsuitable for crop production in general.

3.2. Accumulated temperatures

Approximately 66% of the study area was found to be ‘highly suitable’, and a small portion (7%) ‘unsuitable’. Accumulated temperatures did not affect land suitability for winter wheat because the lowest accumulated value, between January and June, was 1000°C above a base of 0 °C.

3.3. Precipitation

Highly suitable and moderately suitable areas were 50.4 and 31.7%, respectively. Only 13.7% of the study area was unsuitable, with 4.3% of the area in the marginal category.

3.4. Soil management domain

Soil management domain is an important limiting factor for winter cereals within the study area.

Only 28% of the study area was highly suitable and 1.7% moderately suitable; the remainder was marginally suitable (54.4%) or unsuitable areas (16.1%).

3.5. Overall land suitability

The overall suitability map for winter wheat was produced by an overlay of maps of accumulated temperature, precipitation, slope, and soil management domain, using the land suitability requirements for growing rainfed winter wheat as presented in Table 1. Based on these suitability requirements, nearly 8.7% and 7.6% of the study area was currently found to be highly and moderately suitable, respectively (Table 2). The remainder was marginally suitable (28%) or unsuitable (55.7%).

3.6. Change in land suitability under different climate change scenarios

With a scenario of increasing temperatures, there is a shift from marginally and moderately suitable areas to moderately and highly suitable areas (Table 2). As a consequence of different climate change scenarios examined, the ‘highly and moderately suitable’ areas increased in all scenarios except in those where the precipitation decreased.

Figure 1 shows the actual area under different suitability classes under different climate change scenarios and the relative change in contract to the

Table 1. Land suitability requirements for rainfed winter wheat

Characteristic	Requirements for suitability rating			
	Highly suitable	**Moderately suitable**	**Marginally suitable**	**Unsuitable**
Accumulated temperature (°C, Jan-June)	>1750	1500 - 1750	1200 - 1500	<1200
Average total rainfall (mm, Oct–June)	> 450	350-450	250-350	<250
SMD	1, 2	3	4, 5,6	n.a
Slope	0-5%	5-8%	8-20%	>20%

Table 2. Change in percentage area of different suitability classes for rainfed winter wheat under six different climate change scenarios

Area under different land suitability classes (%)						
Scenario:	**1**	**2**	**3**	**4**	**5**	**6**
Temperature:	NC*	0.0°C	0.0°C	+1.5°C	+1.5°C	+1.5°C
Precipitation:	NC	+20%	-20%	-	+20%	-20%
Suitability classes						
1. Highly suitable	8.7	11.2	0.8	9.2	13.3	0.8
2. Moderately suitable	7.6	19.2	10.5	20.8	12.8	10.5
3. Marginally suitable	28.0	14.0	32.2	15.2	21.1	33.1
4. Unsuitable	55.7	55.7	56.5	54.7	52.8	55.6
Total	100	100	100	100	100	100

* No change

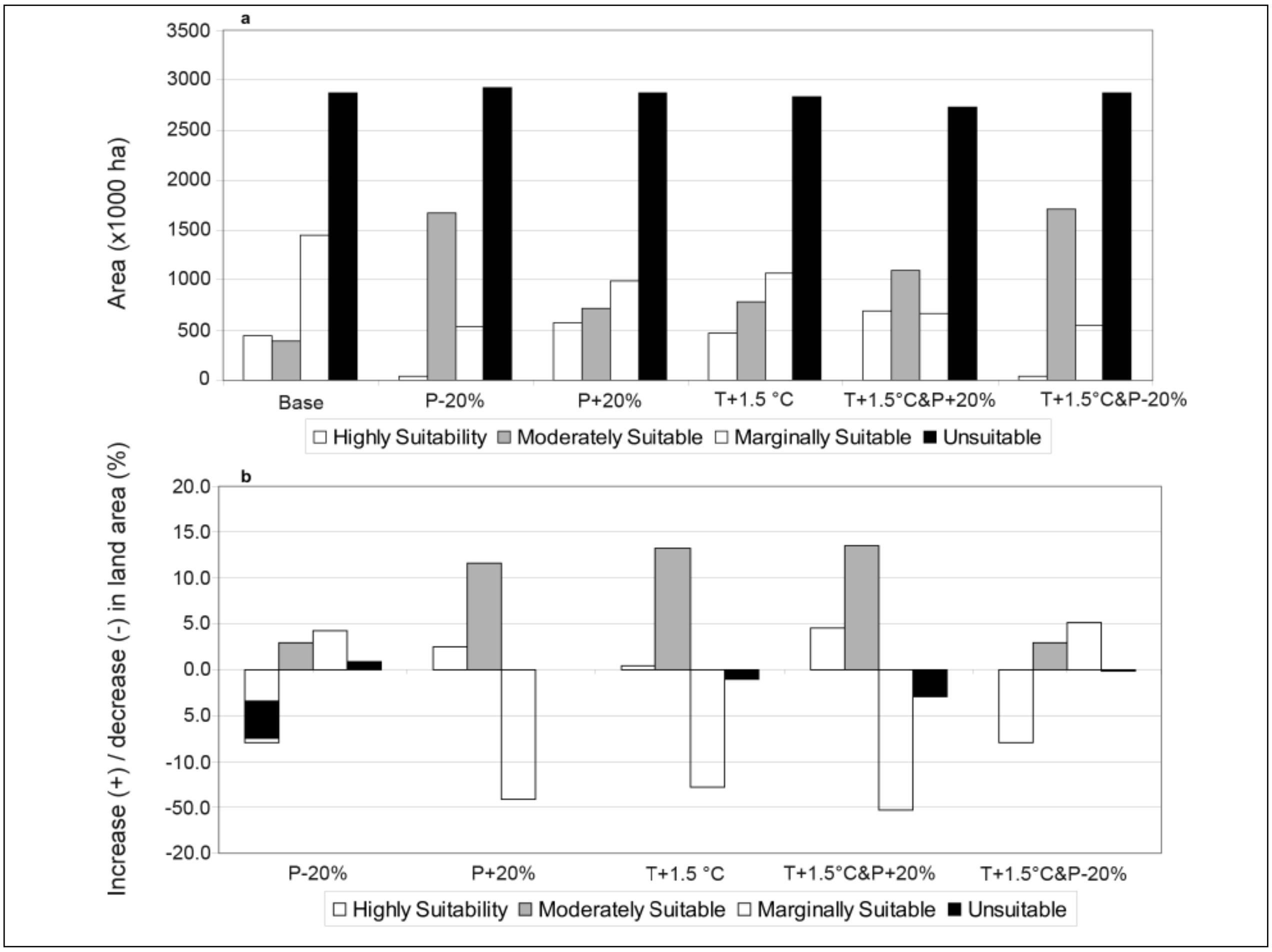

Figure 1 Effect of climate change scenarios on land suitability for winter wheat in the study area: (a) absolute surface area (b) percentage increase (+) or decrease (-) of surface area compared to current condition.

current situation. By increasing temperature alone (T +1.5°C, Scenario 3), the highly suitable and moderately suitable areas increased by 6% and 176% respectively as compared to the current situation. Increasing temperature along with precipitation (T +1.5°C & P + 20%, Scenario 4) increased the highly suitable and moderately suitable areas by 53% and 69% respectively. When temperature increases are accompanied with rainfall decreases (Scenario 5), the area under highly suitable class decreased by - 90% The main reason for this drastic decrease is the increased water stress, not the direct effect of increased temperature, because in Scenario 2 (a 20% decrease in precipitation) the highly suitable area decreased by about 91%.

4. Discussion and conclusions

The physical land suitability for winter wheat is mainly determined by climate, soil and topographic variables. Implementing land evaluation models in a GIS enables an analysis more relevant to policy-making than the original basic data. All the climatic and environmental factors that affect land suitability for winter wheat in the study area are summarized in Table 1. Average accumulated temperature above 0 °C (degree-days) between January and June (the first 6 months of the year) is applied as recommended by McRae (1988) to be a good measure of the heat energy available for plant growth. Also, this variable is used in guiding the management practices. In Western Europe, for example, the best response to fertilizer is obtained when spring application is done after 200 degree-days have been accumulated.

Highly suitable areas have a high potential for production and sustainable yields from year to year. In average years the ground condition here is generally such that it provides an opportunity for sowing the crop at or near the optimum time, while harvesting is rarely restricted by poor ground conditions. Even in wet years land working conditions are acceptable; they do not prevent crop sowing and early establishment, and there is normally sufficient soil water reserves to meet the average requirements of the crop. Moderately suitable areas can allow high or moderate potential crop production, which can get reduced in the years when soil-water is insufficient to sustain full growth, or when crop establishment is unsatisfactory due to untimely sowing or poor soil structure. Marginally suitable areas are those with variable potential production from year to year, with considerable associated risks of low yields, high economic costs, or difficulties in maintaining continuity of output, due to the interaction of adverse climatic conditions with soil properties or disease and pest problems. Unsuitable areas are those that have such serious limitations that they preclude any possibilities of successful sustained use of the land for crop production. The criteria used for classifying land as 'unsuitable', were based in this study area on slope and soil properties rather than on climate.

In general, the climate in the study area is favorable for arable crops such as winter cereals, oilseed rape and food legumes. There is adequate opportunity for autumn cultivations and some, if limited, opportunity for operations in spring.

Although the summer water deficit is large, more profitable crops can be irrigated where necessary, thus avoiding drought.

Slope, an important element of landform, plays an important role in so far as mechanization is concerned. Sys et al. (1991) believe that on slopes steeper than 20% mechanization becomes impossible and for slopes less than 20 percent there are still important variations in productivity according to variation in slope. Navas and Machin (1997) state that, in order to avoid soil erosion and other problems derived from the use of machinery, only land with slopes below 8° should be used. Unfortunately, most of the study area was found marginally suitable and unsuitable; only 42.8% had the acceptable slope category and was therefore highly or moderately suitable for full-mechanized cultivation.

Climate change scenarios have been used to estimate the suitability of land for rainfed winter wheat using the baseline climatic parameters as the means of the period from 1973 to 1998. The general trends show that land classified currently as highly, moderately or marginally suitable is likely to benefit from increased temperature or from increased temperature accompanied with increased precipitation, but is likely to decrease by decreased precipitation, as it would increase water stress.

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Climate change and water: Challenges and technological solutions in dry areas

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Abstract

The Central and West Asia and North Africa (CWANA) region constitutes a large proportion of the world's dry areas. Most of the CWANA countries are already very dry, with low and erratic annual rainfall, and high temperatures during the critical period of crop growth. Climate models predict even lower rainfall and more frequent and intense droughts accentuating water deficiency and affecting the crop productivity adversely. Anticipating these effects of climate change and to develop adaptation options, ICARDA has focused its research on the efficient use of water. small amount of water at critical time could substantially increase yield and water productivity with small amount of water at critical time could substantially increase yield and water productivity. In drier areas, water harvesting techniques can reduce rainwater loss by runoff and evaporation from 90% to 40%. In the badia (steppe) rangelands, microcatchment techniques improve vegetation cover, reduce erosion and increase water productivity. Raised bed planting technique in the irrigated areas could save irrigation water in maize and wheat without yield reduction. Since improved technologies for water management help conserve and protect natural resources and improve food security for the poor despite the effects of climate change, ICARDA will continue its efforts on crop water management with special attention devoted to the anticipated impact of climate.

For example, modeling is being done to simulate wheat production under different scenarios of CO_2 levels, temperature increases and rainfall regimes, and to evaluate the role of supplemental irrigation as one potential adaptation measure to cope with climate change. In addition, studies on genotypic variations in crops under a combination of high temperature and variable rainfall under field conditions will provide new insights.

1. Challenges of the dry areas in the context of climate change

The Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC 2007) foresees a temperature rise globally in the range of 2 to 6 °C by 2100. As a consequence potential evaporation, i.e. crop's evaporative demand, would increase. AR4 further states that extreme weather events such as storms and droughts will most likely amplify. In dry areas, the absolute amount of rain is expected to decrease and variability to increase resulting in adverse effects on agricultural production and water resources.

The CWANA (Central and West Asia, North Africa) region constitutes a large proportion of the world's dry areas and most of its countries are already very dry, with low (100-500 mm per year) and erratic rainfall, and high temperatures during spring, when crop plants make most growth, and much of the summer cropping season. Climate models predict even lower rainfall and more frequent and intense drought events. Drought events have already become measurably more frequent in the last three decades, accentuating the food shortages in the region and enhancing the dependency of many countries on food imports from outside. For example the 1999 drought caused an estimated loss of 40% of cereal production in Syria; the effect in Jordan was even more pronounced where cereal production was less than 1% of the usual amount (Hamadallah 2001). For North Africa, it was shown (http://www.fao.org/DOCREP/MEETING/005/Y6067E.htm) that during the last two decades, Morocco experienced continuous drought events during the period from 1980 to 1985 and from 1990 to 1995 necessitating the import of high quantities of cereals.The country imported about 5 million tons of wheat in 2001 (as against around 2.4 million tons in normal year) because of drought in the preceding years.

In addition to crop production, livestock production has been also affected by drought. In Jordan for example, around 30% of sheep flock died or was slaughtered prematurely in 1997 drought. In Syria, the 1983-84 drought caused a slaughtering of 25% of national flock due to a shortage of feed (Oram and de Haan 1995). The shortage of feed is related to the degradation of rangeland and pasture areas. In Tunisia, the contribution of rangelands to livestock diet has decreased from 65% to 10% (Nefzaoui 2002). In Jordan, the contribution of grazing to sheep diet has declined from 70% of feed requirements in the past to 20-30% at present (Roussan 2002).

The effects of more severe drought due to climate change will be exacerbated by the high population growth in the region. The population of the Near East and North Africa (NENA) region has more than doubled in 30 years (from 1970s to 2000) reaching the 280 million mark and it is expected to reach 500 million in 2030 (UN 2003). This will put more pressure on scarce natural resources such as water. Many countries of this region are already living under water stress conditions (less than 1000 m^3 of available water per capita per year) and others are facing absolute or severe water poverty with less than 500 m^3 of water per capita (Tropp and Jagerskog 2006). The situation will further worsen in 2025 (Fig. 1).

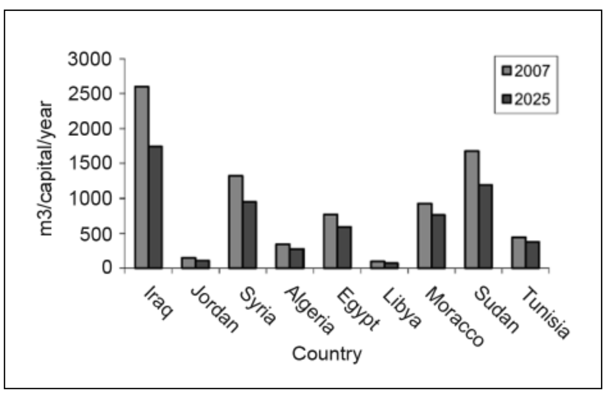

Figure 1. Predicted amounts of water per capita per year for selected countries of WANA (reproduced from FAO 2008).

Lower and more erratic rainfall and higher temperatures due to the climate change will have negative impacts in all the three main agro-systems of the arid zones. In the 'rainfed system', higher temperatures will enhance soil evaporation loss early in the season and expose the crops to more drought and heat during the grain formation phase of the major crops. In the 'irrigated system', with a decrease in water availability more marginal-quality water (saline water, treated sewage water) will have to be used for irrigation, with potential adverse impacts on soil health and crop production. In the 'rangelands', more intense sporadic storms will increase runoff rates and erosion, reducing range productivity and further depletion of groundwater. Combined with this, an increased pressure on rangelands, because of increasing demand for livestock products, would lead to their further degradation.

Despite the problems described above, there is a considerable scope for increase in agricultural production in CWANA because there is large gap between the potential productivity and that currently realized by farmers. A comparison between the farmers' yields and those obtained on experiment stations in Syria, Morocco and Turkey showed that the gap was high (Pala et al. 2009). In the case of Morocco it amounts to 80-98% in rainfed and 40-50% in irrigated areas. In the semi-arid areas of Morocco, Karrou et al. (2009), using the approach developed by Sadras and Angus (2006) to evaluate wheat yield gap, reached a similar conclusion.

One of the approaches that can help farmers to cope with the problems of water shortage and drought described above is to disseminate the information on the existing improved management packages so that they may close the yield gap.However, to face the future challenges of more rainfall reduction and temperature increase, research that aims at the better understanding of climate change and its effects and at the development of new technologies of water use efficiency improvement needs to be promoted.

This paper focuses on technologies related to water, and its efficient use under scarcity conditions.

2. Adaptation options to climate change

2.1. Supplemental irrigation

Many farmers in the dry areas use full irrigation, i.e. supplying enough water to meet (and often exceed) the entire crop water requirement, during the summer. In contrast, a more efficient practice is to apply only supplemental irrigation: i.e. limited irrigation for otherwise rainfed crops, carefully timed to avoid water stress during critical stages such as flowering and/ or grain filling. This not only stabilizes crop yields but also significantly increases water productivity (i.e. the quantity of grain or biomass produced per unit of water). Research conducted in dry areas (Oweis and Hachum 2006; Karrou and Boutfirass 2007) showed that supplemental irrigation significantly improved water productivity and affected saving of water resources without reducing land productivity.

ICARDA's research has shown that water productivity under supplemental irrigation is as high as 2.5 kg of wheat grain per cubic meter of water, compared to 500 grams under rainfed conditions and 1 kg under full irrigation (Oweis et al. 1999).

At a 'Rainfed Benchmark' project site in Tadla, Morocco (RBM 2008), a combination package of production for wheat – early planting with a little supplemental irrigation in spring, was compared with farmers practice. The improved package doubled the wheat yield and water productivity by enabling plants to escape terminal drought and heat stress. The analysis of economic water productivity (EWP) showed the benefits of the use by farmers of improved new varieties, nitrogen rates based on the crop requirement and soil test, and early planting in November in a supplemental irrigation system. The EWP was 2.25 MAD/m^3 before and varied between 2.55 and 2.75 MAD/m^3 after the adoption of the above technologies (Table 1).

The interaction between high CO_2 levels in the atmosphere, high temperature and water deficit – which will all increase with climate change – is not well understood, partly because it is difficult to study in the field. ICARDA is using simulation modeling to understand these relationships.

2.2. Water harvesting

In dry rangeland environments, up to 90% of rainwater is lost by evaporation, either directly from the soil surface or through runoff to salt sinks. Only 10% is used by rangeland plants.

Frequent droughts and consistently low soil moisture levels make it hard to maintain rangeland productivity, and harder still to rehabilitate degraded rangelands. ICARDA has developed integrated water harvesting techniques that improve rainwater use efficiency as well as soil moisture levels, providing better conditions for range plants to grow. These techniques are now being tested and promoted through pilot projects in several countries.

Water harvesting can be applied either at macro level (i.e. runoff from large catchments) or micro level (catchments adjacent to the cropped area). At macro level, runoff water can be collected and stored in small reservoirs to be used for irrigation during dry periods, or allowed to seep into the soil to recharge aquifers. At micro level, runoff water is trapped and channeled to be stored in the soil profile directly supporting the crop. Rainwater that would otherwise be lost as runoff or evaporation is collected and used by plants, livestock, or even people. ICARDA's research has shown that 40-50% of the water otherwise lost through runoff and evaporation can be saved and used by plants. This can be critical to plant survival during drought periods. Water harvesting increases and stabilizes yields. It also reduces erosion: less runoff, less soil carried away, fewer gullies formed.

In Jordan, Syria and some parts of North Africa, ICARDA is integrating simple micro-catchment techniques with other measures to rehabilitate

Table 1. Impact of adoption of improved technologies on economic water productivity in Tadla, Morocco

Economic water productivity	New varieties	Optimum rate of nitrogen	Optimum planting date	Technological package
Before adoption (MAD/m3)	2.25	2.25	2.25	2.25
After adoption (MAD/m3	2.63	2.75	2.55	2.92
Variation (%)	17	22	13	30

Table 2. Effect of water harvesting techniques and contour ridges spacing on biomass water productivity (WP) of atriplex in Jordan

WP (Kg/m^3)	I-CR 4 meters	C-CR 4 meters	I-CR 8 meters	C-CR 8 meters	CW-CR 4 meters	CW-CR 8 meters
Biomass fresh weight	6.05	4.40	2.30	2.15	1.80	1.20
Biomass dry weight	1.40	1.00	0.50	0.50	0.40	0.30

degraded rangelands. Forage shrubs are planted around water-harvesting structures. Field studies (BBM 2008) showed that with more water stored in the soil profile, these shrubs grew rapidly even in near-drought years and this increased vegetation cover, the binding of soil to prevent erosion and the availability of forage for livestock. Moreover, shrub water productivity increased significantly; the biomass fresh weight water productivity increased from 1.2 kg/m^3 to 6.0 kg/m^3 and dry weight water productivity from 0.3 kg/ha to 1.4 kg/m^3 due to the introduction of water harvesting techniques (Table 2).

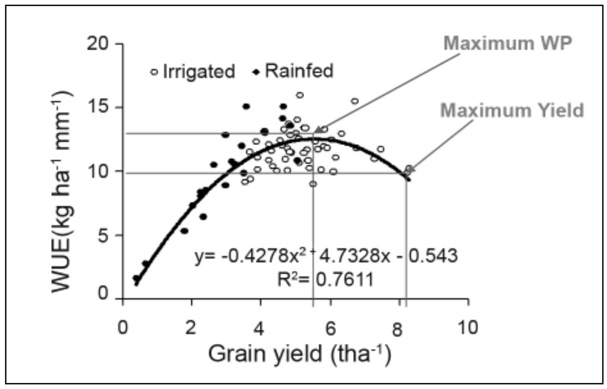

Figure 2. Tradeoffs between water productivity (water use efficiency) and land productivity (grain yield) (Oweis et al. 1998) .

2.3. Techniques to save irrigation water

In irrigated areas of CWANA, there is a need to manage and use irrigation water more efficiently not only because of its scarcity but also to preserve the environment. Traditionally, irrigated agriculture aims at maximizing production per unit land (i.e. land productivity, LP) considering water as a non limiting factor. With increasing water shortage, maximizing the return per unit of water (i.e. water productivity, WP) becomes a priority. So, some trade-off between LP and WP should be accepted. Oweis et al. (1998a) showed that under water scarcity conditions in the Mediterranean region, maximum WP of wheat occurred at the LP level that was below the maximum (Fig. 2). The water saved by maximizing WP instead of LP can be used to irrigate more land in dry areas to increase the total production.

Among the techniques that can save water are the raised bed planting (Sayre and Hobbs 2004) and deficit irrigation (Kirda 2002). Studies on the 'Irrigated Benchmark' site in Egypt (IBM 2008) by ARC-Egypt in collaboration with ICARDA, where these technologies of irrigation were compared with the conventional system (basin flooding), showed that the wide raised bed planting reduced the water consumption by 30%, with correspondingly lower pumping costs. Labor costs for land preparation, irrigation and weed control were also reduced by 35%. The yields were the same or higher and the net incomes increased by 15%. With less water used, crop water productivity increased by over 30% and the net return per unit of water increased by 20% as compared to conventional furrow irrigation. Deficit irrigation (irrigation to meet only part of the water requirement) also saved significant amounts of water, around 1600 m3/ha in maize and 1500 m3/ha in wheat. However, under this technique yield was significantly reduced in one of the two years of the study. Also, to avoid long term salinity build-up problems, irrigation water should be of good quality.

Conclusion

Climate change threatens food security everywhere, but particularly in dry regions, which are already suffering from food shortages. It was shown at the farm level that the improved technologies developed by ICARDA, in collaboration with NARS, can have significant positive impacts on agricultural production. Their wide dissemination can improve significantly farmers' income and livelihood in dry areas by allowing better use and conservation of natural resources. This will contribute to food security under drought and heat stress conditions. To cope with more erratic rainfall, water shortage and hotter conditions due to the predicted climate change, more research on the future impact of climate change and the beneficial effects of the adaptation measures is needed. In 2007, ICARDA launched a new strategic plan to guide its research over the next decade with climate change adaptation as major area of emphasis. Activities will cover four broad areas:

- Basic science to better understand how climate change will impact on crop productivity and water resources;
- Technologies (crops, varieties, natural resource management) to improve climate change adaptation and mitigation;
- Socio-economics research to identify policies to prevent or reduce the impacts of climate change; and
- Building partnerships with other institutions to test and promote new technologies.

It is hoped that the outcome of these efforts would help to enhance the ability of dryland farmers to cope with future climate changes.

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Unmet irrigation water demands due to climate change in the lower Jordan river basin

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Abstract

This study aims at investigating the vulnerability of irrigated agriculture in the Lower Jordan River Basin due to climate change. The approach chosen is to assess unmet irrigation water demands through modelling future water resource availability. The Water Evaluation and Planning System (WEAP) was used to simulate current water balances and evaluate future trends. A set of scenarios was composed of projections on population growth and domestic/agricultural water use efficiencies, a second set of scenarios was based on climate change projections derived from General Circulation Models (GCMs).Results from the model show a general tendency of higher unmet irrigation demands in the highlands where groundwater is the main source of supply. Projected water shortages in irrigated agriculture of the highlands are most pronounced for the Amman-Zarka basin, indicating the high competition for water with growing urban demands. Unmet irrigation demands in the Jordan Valley are comparatively lower, merely pronounced for the North and North East Ghor which receive surface water. Contrariwise, irrigated areas in the southern Jordan Valley are benefiting from increasing urban demands that result in increasing return flows of treated wastewater to these irrigation schemes. A closer look at the King Abdullah Canal (KAC) reveals a buffering capacity in its northern segment that allows mitigating unmet water demands for the North and North East Ghor, if water reserved to supply the southern parts is shifted to the North. Unmet demands in the highlands at the end of the modelled period indicate that the imported volume of water from the Disi aquifer might not be sufficient to reduce the stress on local groundwater aquifers under the projected population growth. Hence, it is recommended to limit groundwater abstractions in the highlands for agricultural purposes. Controlling mechanisms have to be designed and implemented correctly. The use of treated wastewater as a resource for irrigated agriculture should be encouraged further.

Keywords: climate change, irrigated agriculture, Lower Jordan River Basin, water evaluation and planning system (WEAP).

1. Introduction

Jordan, and in particular the study area chosen for this work (Fig. 1), is widely regarded as one of the most water scarce regions worldwide. Available water resources and thus water supply within the basin fall short of total demands. The combination of frequent and long droughts with high population growth, and natural and involuntary waves of immigration from the surrounding countries, has resulted in a severe and persistent water crisis over the last several decades (Batarseh 2006; Al–Karablieh et al. 2006; Scott et al. 2003; Salman et al. 2008). With a population growth rate of 2.2%, current population of 5.93 million is expected to reach 8 million by the year 2025, leading to a continuously increasing urbanization and industrialisation which would exert pressure on the limited water resources, especially in the urban areas of Greater Amman (DOS 2009; Phillips et al. 2009).

In the 21st century, growing problems of scarcity within the region are expected to further increase due to observed trends of rapid global warming and climate change. The changing climate patterns could cause irreversible damage to water and land resources, and lead to significant losses of the ecosystem's production potential (Fisher et al. 2002). Irrigated agriculture might particularly be affected, being the sector with the highest water needs. Both an increasing future demand from competing sectors and a decreasing natural availability of freshwater might strongly influence the relation between urban and rural areas (Scott et al. 2003). Hence, climate change challenges the existing water resources management practices by adding additional uncertainty. The knowledge of these challenges and their impact on hydrological conditions and socioeconomic behaviour of the people are crucial for sustainable development of the water sector. Integrated water resources management (IWRM) will play a major role at this juncture as it enhances the potential for adaptation to change (IPCC 2007).

Studies concerning the effect of climate change on water resources look at a variety of data, including the availability of freshwater resources, and their quality, uses and management. In order to assess the direct impact of climate change on hydrological systems, climatic inputs to hydrological models are modified according to defined scenarios of climate change. However, future water resource availability would depend not only on physiological effects but also on socioeconomic interactions. Furthermore, in water scarce basins, the competition for water from other sectors and different demand priorities would strongly influence water availability.

2. Climate conditions and water resources in the study area

The Lower Jordan River Basin (LJRB) is of major importance because more than 80% of Jordan's water resources and population are there. A demographic boom within the basin increased the population from around 450,000 in 1950 to approximately 4.7 million people today (out of 5.9 million in the country), and it is still growing at an average rate of 2.2% (DOS 2009). Consequently, a strong development of urban centres such as Amman, Zarka and Irbid is occurring, and there is a development of intensified large-scale agriculture - about 59,000 ha of irrigated land (DOS 2008). The vast urban expansion, together with generally improved living standards, has lead to an excessive increase in water demands, putting severe stress on the basin's limited water resources (Venot and Molle 2008). The hydrological and climatic regimes are marginal for agriculture, and already all water resources in the Lower Jordan River Basin are now committed, making the human and natural systems strongly dependent on each other. Because of the aforementioned physical and societal features, water resources in the LJRB can be considered highly sensitive to climate change (IPCC 2007).

Within the area of investigation (Fig.1), two major sub-catchments of the Jordan River system can be found: the Yarmouk river catchment (approximately one third on Jordanian territories) and the Zarka river catchment (almost entirely on Jordanian territories). The Yarmouk river drains an area of 7,000 km^2 with 200 million cubic meter (MCM) of mean annual runoff (Adasiyia gauging station), and the Zarka river catchment covers 3,793 km^2 with approximately 70 MCM of mean annual runoff (Aulong 2009). Together with runoff from side wadis, the total amount of surface water within the LJRB is estimated to be around 550 MCM/year (Venot et al. 2005).

Thus, the annual water balance for the basin is approximately: 300mm of precipitation over the area, divided in 75 mm of runoff and 225 mm of evaporation. Because of the large differences in altitudes on a relatively short distance, the mean annual temperatures and precipitation vary significantly between the Jordan Valley and the highlands. Significant amounts of rainfall mainly fall in the windward mountain ranges. Most of the basins runoff and groundwater recharge is formed there. The groundwater contributes about 50% to the total freshwater supply in the LJRB. The total available groundwater resources of approximately 160 MCM are severely overexploited. Estimations vary between 150% (MWI 2003) and 180% (Venot et al. 2005). As a result, a drawdown of the water table is observed in several wells all over the sub-basins. It is most pronounced for the Amman-Zarka basin, where an average drawdown of 0.5m/year over the past decades was recorded (EXACT 1998). Mainly in the highlands, the overexploitation of groundwater also negatively affects spring discharges and base flow runoff in rivers, the major sources of water for irrigated agriculture in the Jordan Valley. This hydrological connection between the highlands and the JV is of major importance in order to understand the impacts of water resources development in the uplands on downstream users.

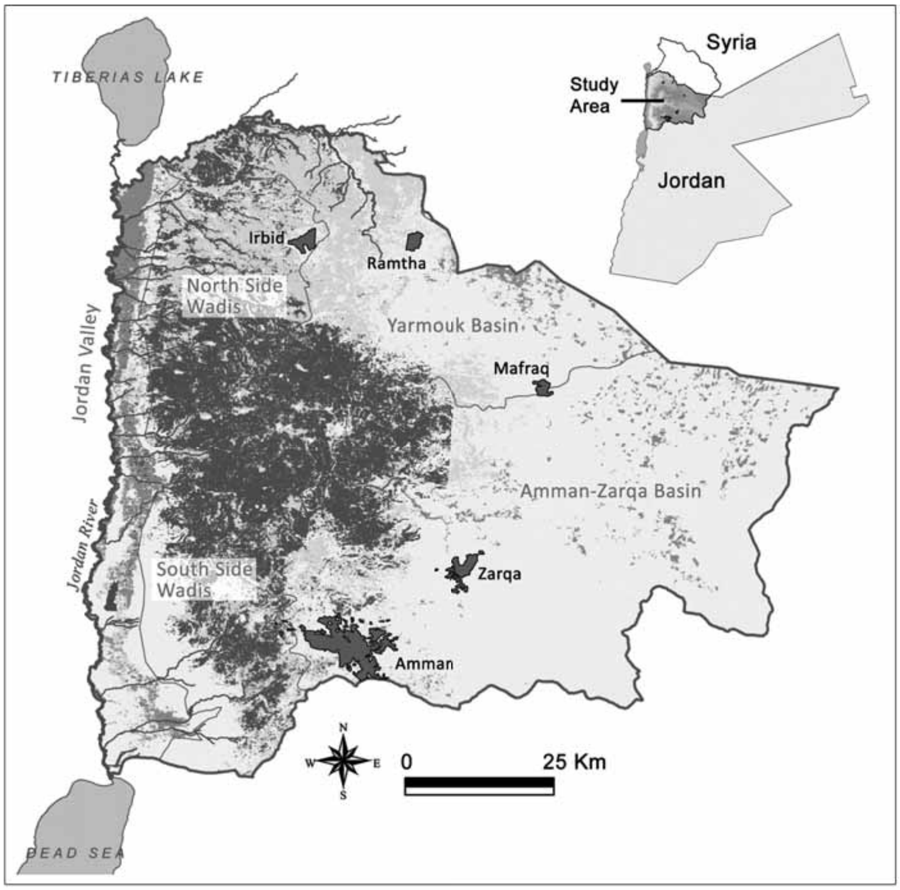

Figure 1. Land use map of the LJRB for the WEAP (Water Evaluation and Planning) analysis.

The current over-commitment of water resources in the LJRB has lead to an interconnection and interdependency of both the JV and the highlands on the one hand, and agricultural and urban demands on the other hand. Climate change in the region that is already noticeable since the 1970s further aggravates this situation. Trend analyses applied to meteorological stations in Jordan have shown for most stations a decrease in precipitation between 8% and 20% over the last three decades of the second millennium. At the same time, mean temperatures have increased between 0.3 and 2 °C, depending on the meteorological station (Freiwan 2008). These trends are likely to continue throughout the 21st century. Projections from three General Circulation Models (GCMs) for Jordan predict an average decrease of precipitation between 0% and 18% for the 45 year period 2006 – 2050. Average temperatures are expected to increase between 0.9 and 1.3°C within the same period of time (Al-Bakri 2008).

The above changes will inevitably affect water resources within the basin. Samuels et al. (2009) simulated the response of the water resources in the Jordan river basin to climate change, shifting rainfall trends including increased multi-year droughts and an escalation in extreme rainfall. They showed that a decrease in rainfall would lead to a comparable decrease in stream flow, about 20–25%. While runoff decreases are expected to be in the same range as the projected decreases in precipitation, the groundwater recharge is believed to be more strongly affected, with a possible reduction by 30% to 50% (Abdulla and Al-Omari 2008; Abdulla et al. 2009).

The projected increase in temperatures is generally expected to have a positive impact on agricultural production systems, resulting in an increase in crop yields (Fleischer et al. 2007; IPCC 2007; Umweltbundesamt 2005). However, this will only occur if the water supply in the future would be sufficient. Furthermore, irrigation water requirements might increase because of the decrease in precipitation (Döll 2002). Matoug (2008) found that a change in precipitation of 10% resulted in changing irrigation demands of approximately 5%, while an increase of evaporation of 10% (corresponding in an increase of temperature of around

+2°C) resulted in an increased irrigation demand of approximately 18%.

3. Objective of the study

Water is the limiting factor in the basin and changes in water resources might negatively affect the irrigated agriculture sector. Abdulla et al. (2009) and Al-Bakri (2008) found that the decrease in precipitation had more pronounced negative impacts on agricultural productivity than the increase in temperatures under climate change scenario. Furthermore, the impacts of climate change on irrigated agriculture should be addressed with due consideration to population growth projections and different management options. The Water and Evaluation and Planning (WEAP) System seems to be a suitable approach to the problem of combining changes in resources availability with changing demand patterns under a defined socio-economic context. In order to assess future water resource availability for irrigated agriculture in WEAP, it is important to know how and to what degree the LJRB and its supply system will be affected by possible future climate changes, and what will be the consequences for the changing demand within the basin. This would imply that all sources of supply and all sectors of demand within the basin have to be taken into consideration.

4. Methodology and approach

A water management support system for LJRB in Jordan has been developed. The system employs the Water Evaluation and Planning (WEAP) System developed by Stockholm Environment Institute (1999, 2005) and also used by other researchers (Roberto and McCartney 2007; Hoff 2007; Purkey et. al. 2008; Al-Omari et. al. 2009). The water resources and demands in the basin are modelled as a network of supply and demand nodes connected by links. The model is calibrated for the base year 2004. WEAP is used to run scenarios based on climate change projections from 2005 to 2050. The relevant parameters used as a baseline scenario are: population growth, domestic water use efficiency, and agricultural water use efficiency. In order to build these time series, step functions are created for the period of projection (2005 – 2050). The relevant parameters to simulate climate change are: catchment precipitation, groundwater recharge, and irrigation water use rate. These time series are created in the form of linear interpolation for the period of projection. In order to assess unmet irrigation demands, the research question is translated into WEAP as shown in Figure 2. Besides considering all sources of supply and demand from all sectors, existing and future inter-basin water transfers (mainly from outside into the basin) have to be included for

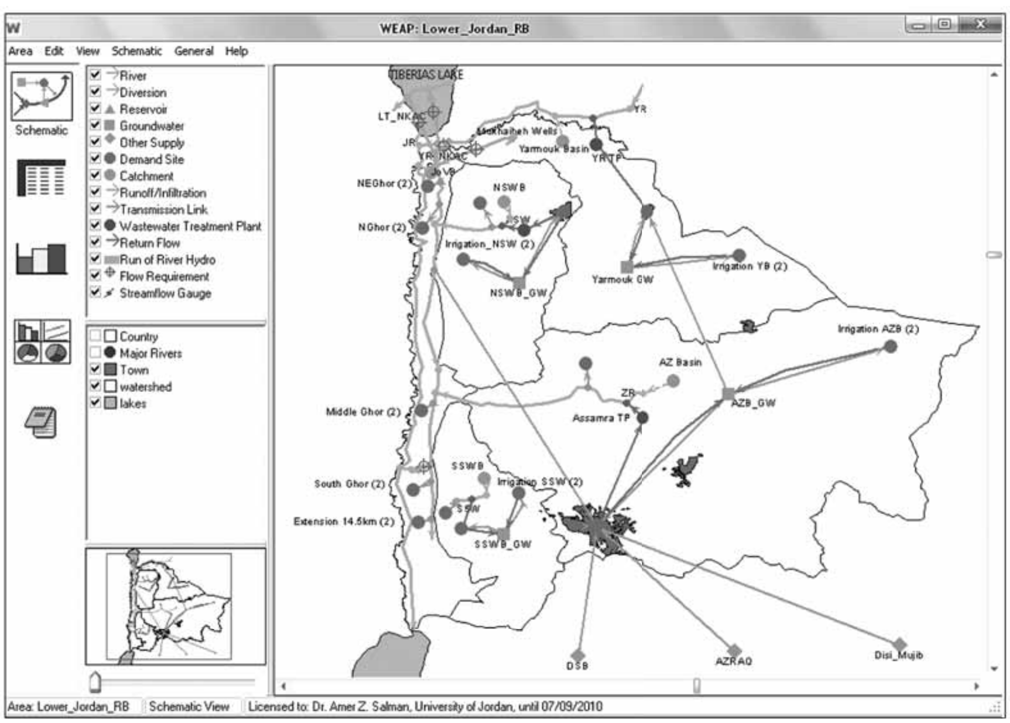

Figure 2. Schematic representation of the LJRB for the WEAP analysis.

realistic modelling. Several simplifications had to be made, due to the complexity of the system. Their merits and demerits are discussed below.

4.1. Temporal scale

The year chosen for the model to serve as base year ("current account") is 2004. The base year provides system information and the dataset, from which scenarios will be built. The period of time for which scenarios are generated is 2005 - 2050. Due to the level of precision of the data available, the model is run on yearly time steps. This has the advantage of a simplified water balance for the basin, because it renders changes in storage negligible and avoids the need to model storage reservoirs. Furthermore, base flow in rivers (aquifer discharge) can be modelled as direct runoff fraction from precipitation.

The disadvantage of yearly time steps is that seasonal variations in supply and demands cannot be modelled. While the annual balance of supply and demand might be even at the end of a given year, shortages of supply might occur during summer with a relative abundance of water in winter months. Hence, the model will only make assertions on climate change trends, and not on climate variation such as extreme weather events.

4.2. Spatial boundaries

The spatial boundaries of the system represent a combination of natural boundaries (surface- and ground watersheds) and state boundaries (Syrian-Jordanian border). This fact hinders the accurate simulation of the hydrological cycle in the northern part of the basin (Yarmouk basin). The formation of runoff on Jordanian territories contributes only a little to the total runoff of Yarmouk River.

In addition, water is diverted to and from Lake Tiberias (according to the Treaty of Peace in 1994). Finally, urban centres of Amman and Zarka are connected to inter-basin water transfers and thus have to be taken into consideration, further complicating the delineation of system boundaries.

4.3. Relevant system components and configuration

The model is organized in a way that each sub-watershed is principally independent from the others. Thus, each basin has its own water resources and demand sides. The connection of the sub-basins with each other is through rivers, and transmission and diversion links.

As shown in Figure 1, each sub-basin is represented by a catchment node that contains all relevant information on area, land use and climate conditions of the relevant sub-catchment. The catchment node simulates runoff to the river through the "effective precipitation" parameter that allows a percentage of precipitation to bypass evapotranspiration. In addition, a groundwater resource is included in every sub-catchment of the highlands. Although the interaction of groundwater with rainfall and surface water is not modelled here, the resource is equipped with information on natural recharge and abstraction volumes. Finally other sources of supply are marked as green diamonds.

These are the main inter-basin water transfers: the supply of freshwater to Amman from the Dead Sea Basin and from Azraq. Further water transfers from outside into the basin, such as the planned Disi-Pipeline and supply from the Wadi Mujib Dam are not active in the "current account" year of the model, but will be activated for the scenarios.

For simplification purposes, each sub-catchment contains one urban demand site and one irrigated agriculture demand site, centralizing all domestic/industrial and agricultural activities of the catchment. An exception is made for the Jordan Valley that consists of 5 agricultural and no urban demand nodes. The urban demand sites are equipped with an annual activity level (population), an annual water use rate (per capita) and information on consumption (i.e. water that does not return to the system). Agricultural demand nodes are equipped with the size of the irrigated area and annual irrigation water requirements (per hectare).

The demand nodes are connected to the resources with a transmission link for the supply, and with a return flow link for water that flows back and infiltrates to local groundwater or returns to rivers either through a treatment plant or directly.
The King Abdullah Canal (KAC) is represented through a river with two segments. The northern segment receives water through diversion links from Yarmouk River, Lake Tiberias and the Mukheibeh wells. It also receives water from the North Side Wadis basin. The southern segment of

the canal receives water from the northern segment and further downstream from Zarka River. This schematic representation is simplified compared to the real situation, where the canal and its balance are divided into four segments. Furthermore, in the designed scheme, the Middle Ghor will receive water only from below the inflow point of Zarka River, whereas in reality it receives water from above and below the mixing point.

4.4. Baseline

For the "current accounts", all supply and demand nodes are provided with 10-year averages of the data required. The model is calibrated in a way that all demands in the basin are met for the baseline year. This does not necessarily represent reality, but was inevitable due to the fact that the annual water use rate per hectare of irrigated land, with a diverse cropping pattern, could only be derived from the amount of water supplied to a specific area. Hence irrigation water demands appear to be covered. However, this does not negatively affect the analysis, as the objective is to investigate supply and demand patterns under increasing pressure on the system. Another simplification is that some schemes in the model are not equipped with maximum flow requirements. In the case of the Asamra treatment plant, this means there is no maximum daily capacity due to technical limitations. Hence increasing volumes will be returned to the river without constraints.

4.5. Scenarios

Altogether, twenty scenarios are developed in order to assess the impact of climate change on water resource availability and demand patterns. A range of incremental scenarios is built upon the Story and Simulation (SAS) scenarios developed by GLOWA Jordan River project (Lübkert 2008). The scenarios are described below in detail.

4.6. Story and simulation scenarios

The SAS approach generates consistent and realistic scenarios through an iterative process between scientists and stakeholders (Alcamo 2005; Alcamo 2008). The scenarios look at possible political and economic developments in the region, and derive quantitative and qualitative projections. From the four developed SAS scenarios, the future developments of population growth, as well as changing water use efficiencies in the domestic and agricultural sectors were used for this study. The four SAS scenarios are: 'Willingness & Ability', 'Modest Hopes', 'Poverty & Peace', and 'Suffering of the Weak & the Environment'. A description of the scenarios is given below:

- ***Willingness & Ability scenario:*** It is the most optimistic scenario and consists of peace and economic prosperity. It is assumed that water saving technology will be widely developed in order to improve the overall water availability. It projects high water use efficiencies in the agricultural sector. However, due to the economic boom and a growing industry, the population growth is expected to continue increasing.
- ***Modest Hopes scenario:*** It assumes that there will be no peace agreement in the near future between the states sharing the water resources, but economic prosperity is nevertheless expected. Steep population growth and improvements in water use efficiencies are expected.
- ***Poverty & Peace scenario:*** It is composed of a peaceful development in the region, but without economic prosperity. Due to economic recession, the shortage of water resources continues and the water stress cannot be solved. This is reflected in a limited capacity of water use efficiency improvements due to a lack of financial means.
- ***Suffering of the Weak & the Environment scenario:*** Among the four scenarios, this is the worst case scenario. Neither peace nor economic prosperity is expected to occur in the near future. This situation results in modest population growth and decreasing water use efficiencies.

4.7. Incremental scenarios

In order to simulate climate change, incremental scenarios are derived from results of the GLOWA JR project, projections from General Circulation Models (GCMs) and outputs from hydrological models run by Abdulla et al. (2009), Freiwan (2008) and Samuels et al. (2009). Future climatic scenarios from the GLOWA JR project show an increase in the yearly mean temperature up to 2.5°C and a slight decrease of the annual precipitation (GLOWA JR 2007). Projections from three GCMs in Jordan predict an average increase in temperatures between 0.9°C and 1.3°C within the period 2010-2050 and a decrease in precipitation by up to 20% (Al-Bakri 2008). Abdulla et al. (2009) studied a set of 19 climate change sce-

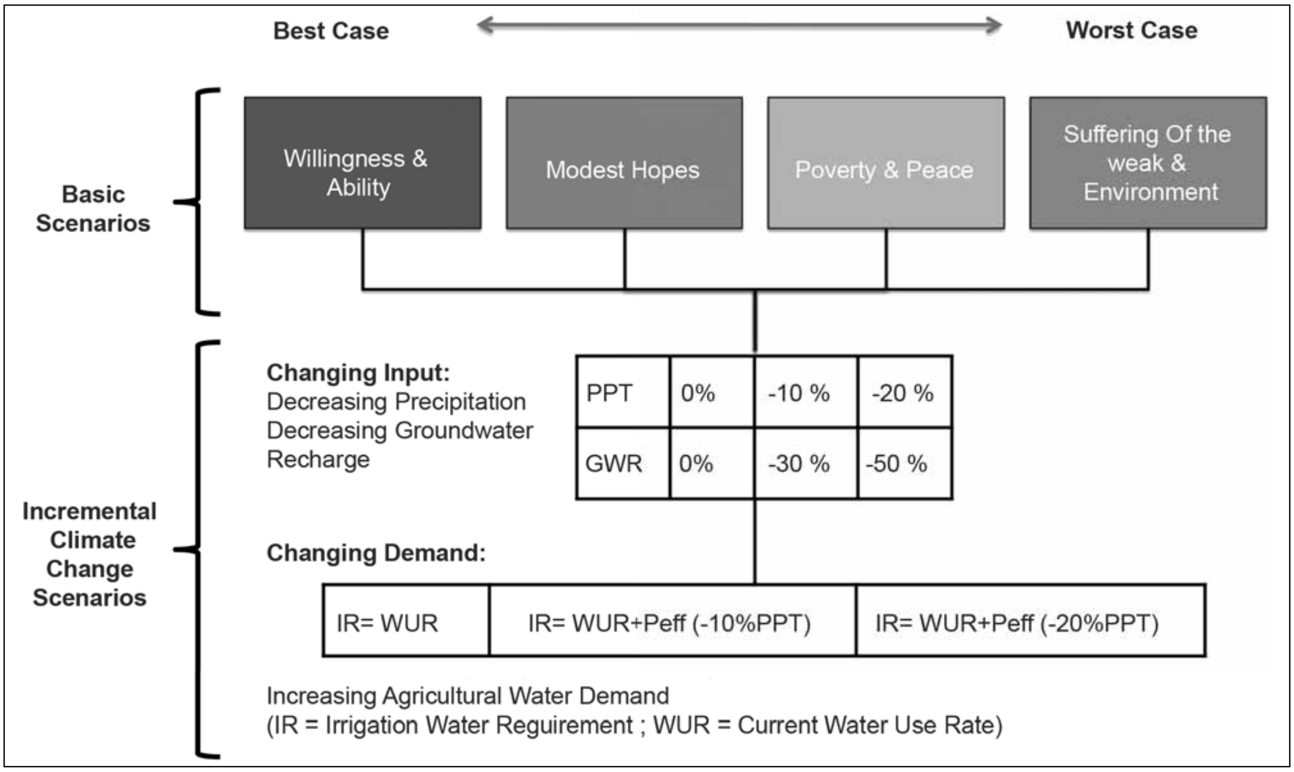

Figure 3. Scenarios developed for the assessment of climate change impacts in WEAP.

narios representing combinations of mean annual temperature increases (1°C to 3.5°C) and decreases/increases in rainfall in the range of 0% to 20%. The results showed that a climate warming with a maximum of 3.5°C increase in temperature and no change in rainfall would have insignificant impact on the runoff. The effect on groundwater recharge was more pronounced.

For each SAS scenario within the WEAP simulation, precipitation is incrementally reduced, from 0% to -10% to -20%, to simulate different surface water availabilities. At the same time, the recharge to groundwater is reduced by 0%, -30% and -50% respectively. The reduction of these input parameters is done by simple interpolation from 2005 - 2050, representing a linear decreasing trend from the baseline year onwards to the last year of projection.

A third set of scenarios aims at simulating changes in the water use rate on the demand side. With this, the possibility of increasing irrigation requirements due to decreasing rainfall is reflected. Calculating the changed amount of average effective rainfall over each irrigated area and adding it to the annual water use rate would permit this. Hence the scenarios of changing demand are built upon the scenarios of incrementally decreasing precipitation.

5. Results and discussion

The scenarios were evaluated with regard to unmet irrigation demands and water availability within the natural or artificial supply schemes. Due to the high number of scenarios, only a few results are presented here.

5.1. Changing water availability in supply schemes

According to the model design, the driving forces for volume-wise changes in surface water schemes are: a changing natural inflow (runoff from precipitation), changing return flows (from growing urban centres), and changing withdrawals (increasing water demands). Figure 4 shows the development of annual runoff volumes from 2005 - 2050 for the best-case scenario (“Willingness”) and the worst-case scenario (“Suffering”). In both cases, the total runoff volume is increasing from approximately 85 MCM in 2005 to 140 MCM in 2050. This is explained by the relatively strong population growth for all SAS scenarios, resulting in an increasing return flow of treated wastewater

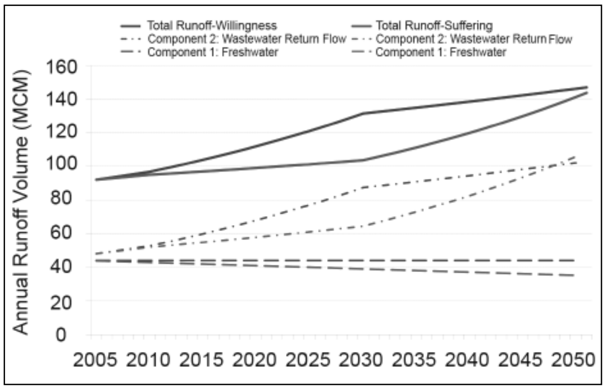

Figure 4. Annual runoff volume for Zarka River for best-case and worst-case scenarios.

through the treatment plant. Consequently, the relative contribution of inflow from the two major sources to the Zarka River changes over time.

A reduced amount of freshwater, and a significantly increased amount of treated wastewater might lead to further dilution problems. At the beginning of the modelled period, the two components are of the same magnitude, whereas towards the end the treated wastewater mixes with freshwater at the ratio of 3:1. This trend of change in relative contribution of inflow to the Zarka River is observed for all scenarios. It is less pronounced for scenarios that predict no climate change or 10% decrease in precipitation. The trend of wastewater return flow is increasing for all scenarios, mainly depending on the projections of population growth and domestic water use efficiencies.

The water availability along the KAC from North to South is also subject to changes. The situation presented in Figure 5 is again based on the best case and worst case scenarios. Both are modelled with moderately increasing irrigation water requirements for the compensation of 10% decrease in precipitation.

The fact that inflows from Yarmouk, Lake Tiberias and Mukheibe wells are in line for both scenarios is explained by the modelling under the same climate change scenario. Withdrawals are in line by the fact that in both cases demand sides are withdrawing the maximum amount possible. Furthermore, demand sides shown here are modelled for both scenarios under the same incremental water requirement scenario. The difference in inflow from the North Side Wadis is linked to the different population growth projections. The 'Willingness' scenario, with a higher population growth will result in an increased return flow from urban centres, mainly Irbid.

With decreasing inflows and increasing demands, the gap widens southwards for the northern segment of the canal for both scenarios. As shown in Figure 5, approximately 30 MCM are available at the end of the northern segment in 2005, to be delivered to the southern segment for the supply of the Middle Ghor and South Ghor. In 2050, this amount is expected to be fully used up by withdrawals from the northern segment of the canal (for the 'Suffering' scenario). Consequently, future developments bear the risk of a sharply reduced supply of water from the northern segment to the southern segment of KAC. On the other hand, this indicates a certain buffering capacity within the KAC, meaning that reduced inflow to or increased withdrawals from the canal do not immediately affect demands.

The southern segment of the canal (SKAC) shows a different pattern. Compared to 2005, the available amount of water in the canal is generally increasing for both scenarios. Despite the fact that the inflow from northern segment is decreasing to zero in the 'Suffering' scenario, the strong increase from Zarka River inflow into the canal compensates for the losses. Here again, this is more pronounced for the 'Willingness' scenario due to its higher population growth projections and the related increase in return flow from the urban centres Amman-Zarka. Relatively parallel decreasing water availability from the demand nodes onwards is explained by the running of both scenarios under same conditions of increasing water requirements. The difference in agricultural water use efficiencies between the two scenarios is comparatively low and hence not noticeable in the chart scale of Figure 5.

The modelled results for KAC reveal an interesting observation. Despite the fact that the LJRB has been exposed to an increasing stress through reducing natural supply and increasing demands, the KAC seems to face only little shortage of available water in the future. While in 2005 agriculture in the southern Extension is barely supplied, water in the 2050s seems to be sufficient, even providing a buffering capacity in case of droughts for both, the worst-case and best-case scenario. However this finding has to be regarded with reservations. Although the Middle Ghor, South Ghor and the

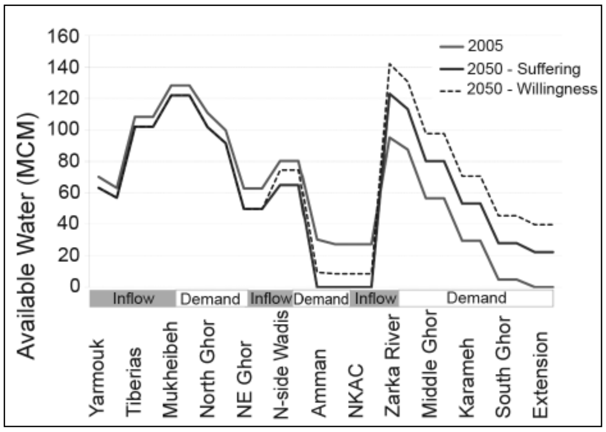

Figure 5. Changes in water availability along the King Abdullah Canal (KAC).

Extension don't seem to face demand gaps in the future, the water for supply will entirely stem from Zarka River and its blended water resource. This blended water will itself carry an increasing component of treated wastewater, as was shown in Figure 4. Hence, concerns of water quality, the risk of soil salinization as well as consequences for cropping patterns will have to be tackled.

5.2. Unmet irrigation demands

Due to the fact that environmental flow requirements were not modelled for rivers, all the water within the supply schemes is available for meeting the demands. This does not necessarily represent reality, but it does not affect basic statements made in this study.

Figure 6 shows the unmet irrigation demands of the Jordan Valley for the two SAS scenarios ('Willingness' and 'Suffering') as well as for all incremental scenarios that simulate climate change in the basin. The results show that unmet demands occur only for the North Ghor and the Northeast Ghor, whereas the supply of all other demand sites in the JV is met. For the best-case scenario (i.e. 'Willingness'), unmet demands remain generally very low. While between 2010 and 2030 no significant unmet demands can be observed, the North Ghor and Northeast Ghor seem to have a considerable shortage of water for the first time in 2040. However, this shortage occurs only for the incremental scenario that exerts the strongest

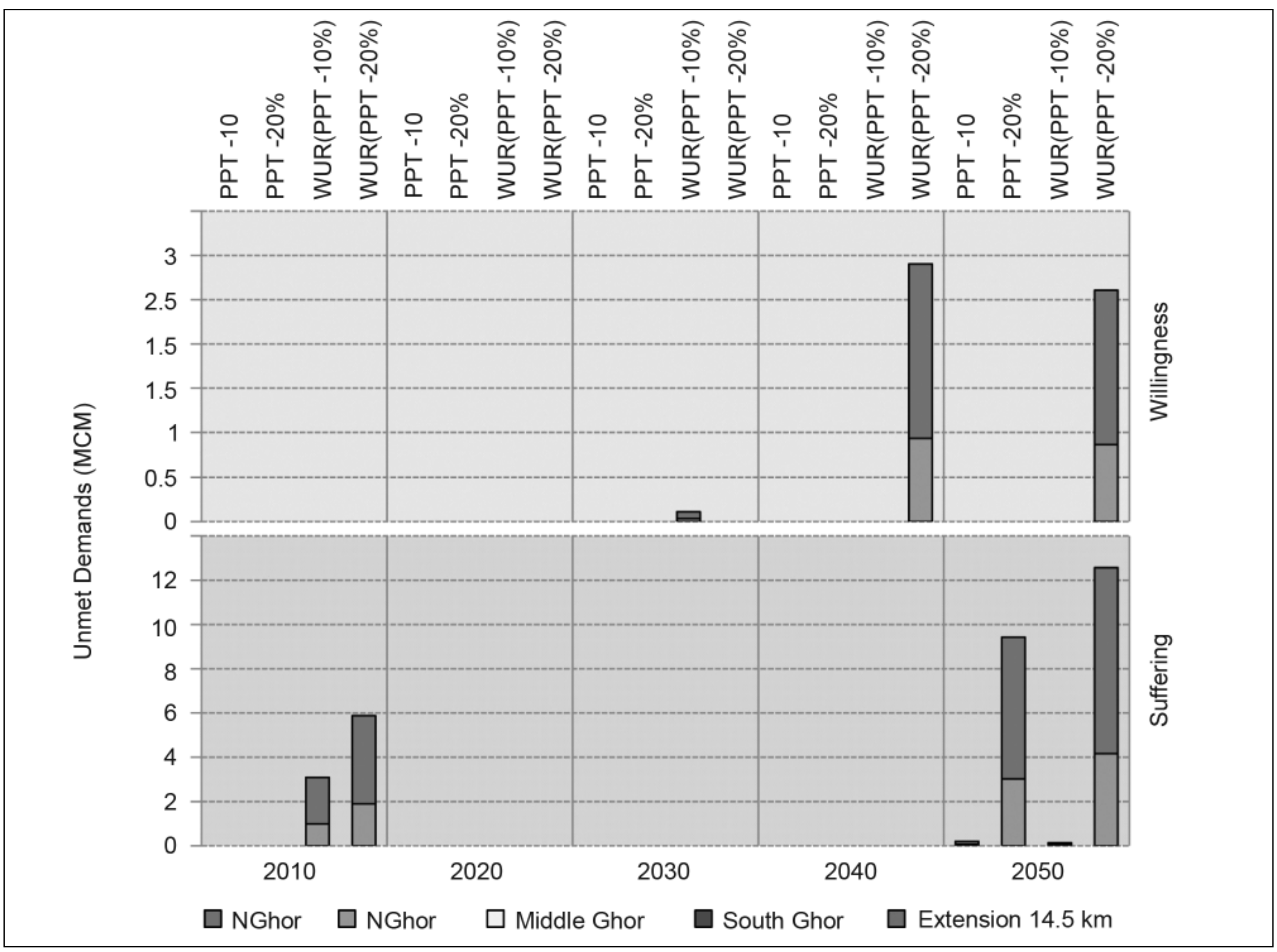

Figure 6. Unmet irrigation demands for the Jordan Valley.

stress on the basin, i.e. the climate change scenario with a 20% decrease of precipitation in addition to an increase in irrigation water requirements. The slight decrease of unmet demands towards 2050 is explained by the relatively strong increase in water use efficiencies of both the agricultural and domestic sectors in the 'Willingness' scenario.

For the 'Suffering' scenario, the pattern of unmet demands slightly differs with a generally higher magnitude compared to the 'Willingness' scenario. A water deficit occurs already in 2010 for the North and Northeast Ghor, for both incremental scenarios that project decreasing precipitation patterns along with an increasing water demand. While the demands are satisfied between 2020 and 2040, a gap between supply and demand is found for all incremental scenarios in 2050. The gap is significantly more pronounced for the scenario of a 20% decrease in precipitation and its related sub-scenario of increasing irrigation demand. The decrease of unmet demands to zero in the 'Suffering' scenario for the period 2020 - 2040 can be explained by the effect of increasing water availability in the basin through the Disi-Pipeline.

Starting to be active from 2012, this additional import of water from outside of the basin reduces the water stress for the major urban centres. Hence, it also reduces the pressure on sources of supply to the urban sector such as the diversion of water from NKAC to Amman. However, from 2050 onwards this positive effect seems to be wiped out by strongly increasing demands, with the unmet demand of North and Northeast Ghor reaching 12MCM for the worst case scenario.

In the highlands, potential water deficits within irrigated agriculture reveal another picture. The gap between supply and demand is generally higher compared to the JV, and is present for all the years and all simulated scenarios.

The four incremental scenarios of climate change are plotted from left to right: decreasing precipitation (-10%, -20%) and increasing water use rates

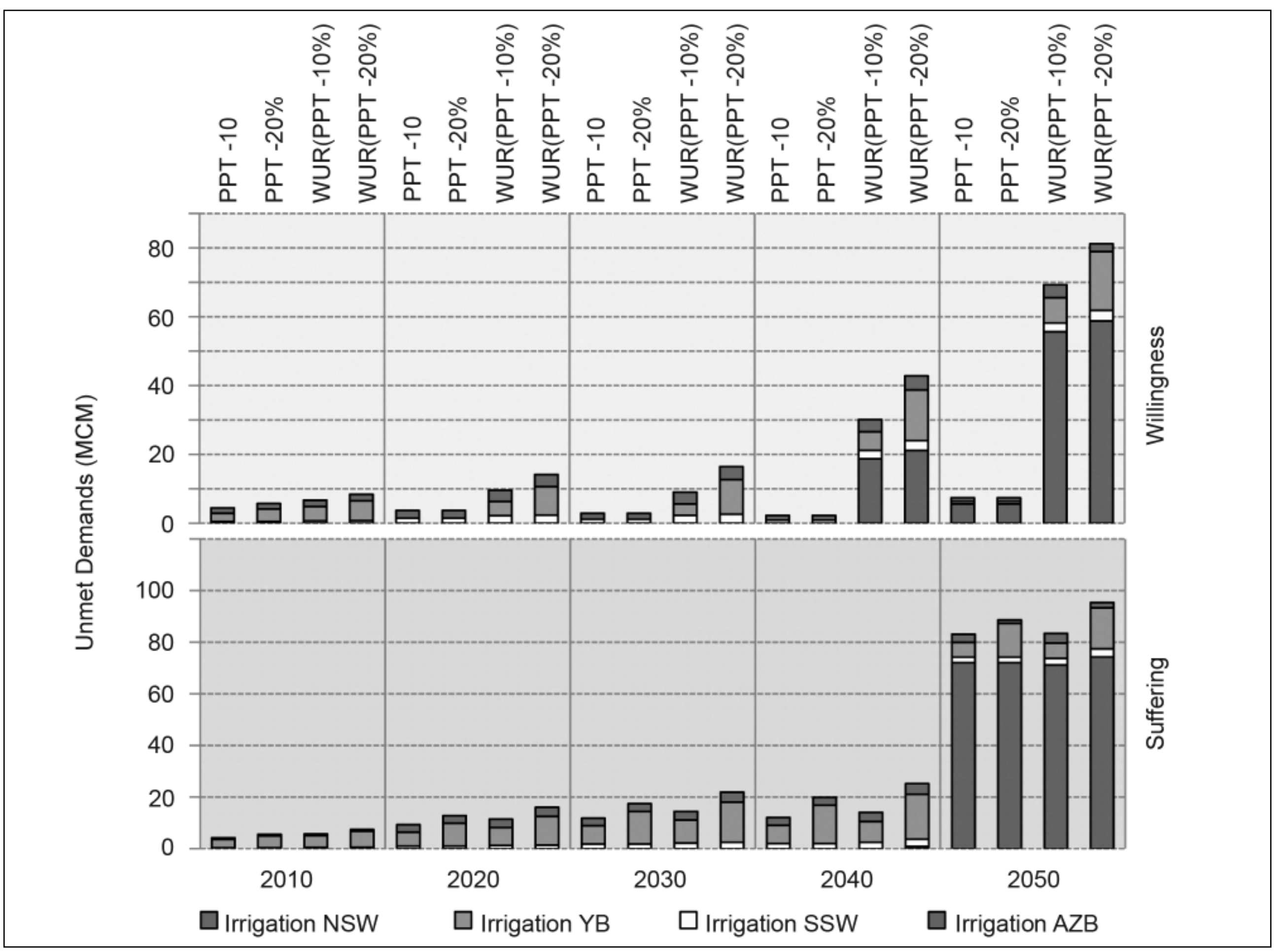

Figure 7. Unmet irrigation demands for the highlands.

according to the respective decrease in precipitation as can be seen in Figure 7. The unmet demands are most pronounced for irrigation schemes of Yarmouk and Amman-Zarka basins, and less pronounced for irrigation in the North and South Side Wadi basins. Another interesting difference is evident for the 'Willingness' scenario, where decreasing precipitation scenarios without increasing irrigation requirements seem to be less harmful in all the years, compared to decreasing precipitation scenarios with increasing irrigation demands. This is explained by the already existing stress on groundwater resources in the highlands, where every additional water requirement will lead to further overexploitation of the aquifers.

Although most affected by the simulated climate change scenarios, irrigated agriculture in the Amman-Zarka basin faces shortages of water only towards the end of the modelled period.

Here again, the Disi conveyor seems to play a major role. According to the scheme of the model (Figure 2), the conveyor delivers water only to the Amman-Zarka basin. Hence the pressure on groundwater resources in this basin is significantly reduced, allowing agriculture to get its full water requirement. Nonetheless, the fact that irrigated agriculture in the Amman-Zarka basin faces crucial demand gaps at the end of the modelled period shows that the imported volume of water form Disi basin will not be sufficient under the projected population growth.

Comparing the results for the Jordan Valley and the highlands, it can be said that the impacts of climate change are higher and more consistent over time for agriculture in the highlands. According to the simulation, only the northern part of the Jordan valley is affected. Irrigation schemes in the middle and south of the JV have not revealed unmet demands for all simulated scenarios. The irrigation schemes supplied by the northern segment of KAC, namely North and Northeast Ghor, start responding only when the 33MCM of water reserved in order to supply the southern segment of KAC are used up. In line with Figure 5, this again indicates a certain buffering capacity within the KAC.

6. Conclusions and recommendations

The vulnerability of irrigated agriculture within the LJRB was assessed through analysing future water resources availability with changing demand patterns under a defined socioeconomic context. Using the WEAP modelling environment, the water balance of the basin was defined for the baseline year 2004 by taking into consideration all relevant sources of supply, as well as demand sides of all sectors within the basin. Future trends from 2010 - 2050 were analysed for a set of scenarios consisting of four SAS scenarios and incremental climate change scenarios. The SAS scenarios were used to project population growth and changes in water use efficiency, and the climate change scenarios simulated changes in water availability and changes in agricultural demand patterns. The analyses were done on an annual basis, thus, only addressing climate change and not climate variation.

The study clearly showed that agriculture depends on the relationship between the natural environment and human society. Modelled results have shown that unmet demands in irrigated agriculture are likely to occur in the future, especially in areas that are in direct competition with urban sectors.

The shortages in water for irrigation were most pronounced in the highlands, where agriculture and urban centres overuse the same groundwater sources. Quantitative results have to be considered with reservations, as groundwater resources could not be linked to other basins sufficiently, and their interaction with surface water was not modelled to the extent desired. However, bearing in mind the model limitations, qualitative results obtained from the model are comprehensible and certainly valid. Modelled observations are in line with several measures already being currently taken by the government or international donors. In order to decrease agricultural groundwater abstraction, measures such as the freezing well-drilling or implementing taxes and other pricing policies on groundwater abstraction are being taken by the government (MWI 2009; Venot et al. 2007). To address quality concerns related to the reuse of blended water, monitoring has been put into place (Charkasi 1999), and recommendations for proper use have been developed (GTZ 2006).
It is recommended to further limit agricultural groundwater abstractions in the highlands. Controlling mechanisms have to be implemented correctly to accurately monitor the status of groundwater resources. The use of treated waste water for irrigated agriculture in the highland should be

encouraged. If monitored appropriately, it would be a valuable option to expand agricultural areas, or to shift the supply from freshwater to treated wastewater for existing irrigation schemes. The WEAP application should be further developed in order to estimate unmet irrigation demands with higher accuracy. The natural system has to be modelled more realistically. This can be done by modelling catchments with the soil moisture model integrated in WEAP, a two bucket model that can model surface-groundwater interactions. Furthermore, climate change projections for water resources coming from outside into the basin have to be taken into consideration. Lake Tiberias and the Syrian catchments of Yarmouk are significantly contributing to water availability within the LJRB; hence the transboundary basin as a whole should be modelled in order to obtain accurate quantitative results. It is also recommended to increase the temporal resolution of the WEAP application, by using monthly time steps for all relevant data inputs. In this way, seasonal variations can be assessed, and the overall accuracy of estimates is enhanced.

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Strategic planning for water resources management and agricultural development for drought mitigation in Lebanon

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Abstract

Dominated by the Westerly and the low pressure fronts coming from North and Central Europe, Lebanon has relatively favorable conditions of annual precipitation compared to other countries in the Near East region. However, significant decrease in rainfall patterns was observed during the last few decades. Moreover, increases have been found in the annual averages of daily maximum and minimum temperatures, and the number of summer nights. It is predicted that by year 2050, Lebanon will experience a reduction in average rainfall during the wet season. Besides, available surface and groundwater resources of the country are insufficient to support the required agricultural production. Furthermore, reduced vegetation cover due to deforestation, overgrazing and poor surface management of cultivated lands have led to reduced infiltration rate, increased runoff and soil erosion, and a decline in groundwater recharge. Due to this alarming situation, various efforts have been recently made in Lebanon to assess and predict the impacts of climate change on water resources and agriculture. However, providing a national strategy that can be applicable for the whole country is very difficult, but long-term policies at both national and regional levels, assessing the vulnerability of water and agriculture in each area, nevertheless, need to be developed.

Keywords: agricultural development, climate change, groundwater recharge, water resources.

1. Climate and water resources in Lebanon

The climate of Lebanon is typically Mediterranean, humid to sub-humid in the wet season to sub-tropical in the dry season. The National Meteorological Service (NMS) defined eight eco-climatic zones, primarily on the basis of rainfall. According to their geographical situation, the eco-climatic zones are distributed as follows (Figure 1):

a b

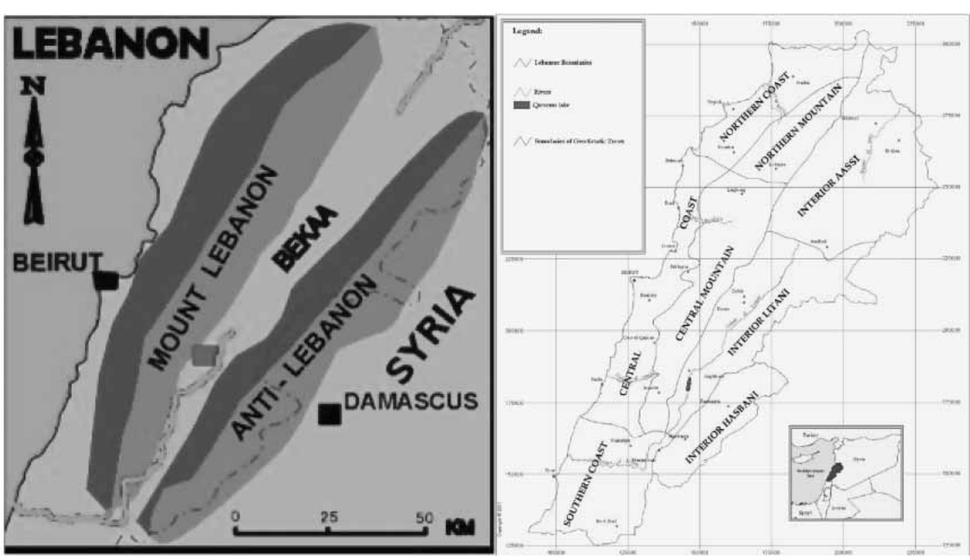

Figure 1. Lebanon geo-physiological (a) and geo-climatic zoning (b) (LNAP 2002).

- The coastal strip, including northern, central and southern coastal zones;
- The mountains, or the Mount-Lebanon, which are divided into two zones; northern and central; and
- The inland area divided into three zones: northern, central and southern Bekaa Valley.

While the coastal and mountainous areas are characterized by abundant rainfall distributed over winter season, the Bekaa Valley has a semi-arid to continental climate with unpredictable rainfall and recurrent drought. The rural communities living there mostly depend on rainfed cropping.

In the central parts of the Valley the climate is semi-arid, whereas in the northern part it is almost arid to continental, since it is separated from the sea effect by high and ridged mountain chain, with height reaching 3,000 m above sea level. In the southern Bekaa Valley, a sub-humid Mediterranean climate is dominant, with more reliable rainfall during winter time.

1.1. Precipitation

Precipitation constitutes the only renewable water resource in Lebanon, with annual average over the country varying between 600 and 800 mm. The long-term data indicate that 95% of the precipitation occurs between October and April, and the remainder 5% between May and September. Average annual precipitation on the coastal strip ranges between 700 and 1,000 mm, with a trend for increase northward (Figure 2).

The Mediterranean Sea acts as a primary source for moist air masses, which generate high rainfall over the coastal areas and the Mediterranean-ward slopes. Frontal Mediterranean cyclones, associated with the south-westerly air mass, create conditions favorable for heavy rains on the coastal and western mountains during late autumn and early spring. The northern and mid parts of Mount-Lebanon chain form a natural barrier to the transversal movement of the clouds, resulting in heavy precipitation, which sometimes exceeds 1,500 mm, mostly as snow. Whereas the western foothills of Mount-Lebanon are climatically Mediterranean, the eastern foothills are less humid, with sub-Mediterranean climate and an average rainfall of 600 mm. As a result, there is a period of stable rainfall between November and April with a peak in January, the precipitation ranging from 50 mm at El Qaâ in the northern Bekaa Valley to 150 mm at Ksara in the central Bekaa Valley. On the mountains, average rain recorded in January varies between 350 mm at Laqlouq in the northern Mountains, to 300 mm at Jezzine in the central Mountains. At the coast it is around 200 mm.

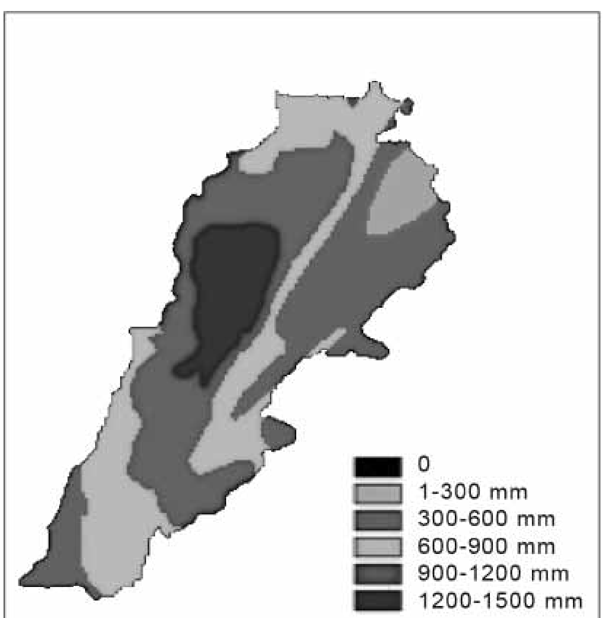

Figure 2. Map of precipitation ranges (Careaux-Garson 2001).

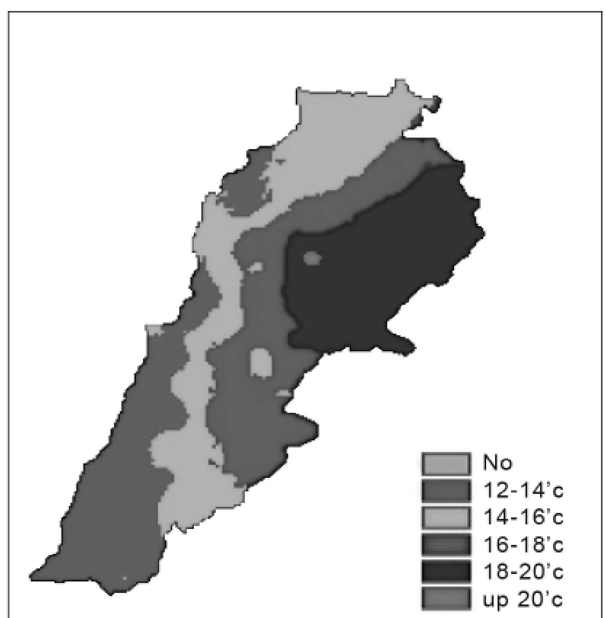

Figure 3. Map of temperature classes (Careaux-Garson 2001).

1.2. Temperature

Mean annual temperature varies on the coast between 19.5 °C and 21.5 °C. It decreases approximately 3 °C for each 500 m elevation. At 1,000 m, mean annual temperature is around 15 °C and becomes 9 °C at 2,000 m a.s.l (Figure 3). The lowest temperatures, recorded in January, vary from 7°C at the coast to –4°C on the mountains. The highest temperatures are in July, exceeding 35°C in the Bekaa Valley. Similar temperature can also be experienced at the coast, but with less adverse effects due to higher relative humidity.

Drought has been a recurrent phenomenon in Lebanon in the last few decades, with abnormal warm conditions prevailing all over the country and the Middle East in general. A warming trend started in early 1990s and continued during the last decade.

In the last 5 years, annual mean temperatures were above historical average and total rain was below the normal. A significant drought was observed during the 1998/1999 rainy season, when, in some places, only half of the long-term average rain was registered. Severe drought conditions prevailed in the central and northern parts of the Bekaa Valley.

1.3. Water resources

Lebanon has relatively a favorable hydrological position in comparison to other countries in the region. The average yearly precipitation results in an average flow of 8,600 billion cubic meter, giving rise to 40 major streams and rivers, of which 17 are perennial, and more than 2,000 springs. However, despite this seemingly good supply, Lebanon experiences serious water shortages in summer even during the wet years. This is because Lebanon's water storage capacity is very low and there is a deficiency of the water delivery systems and networks (AQUASTAT 2008).

About 80% of the total annual stream flow occurs during winter. The deficiency in water flow during summer can be managed if winter flow could be stored into reservoirs and used in dry periods. Indeed, full winter surface flow storage is necessary unless other water sources are available during the irrigation season. The net storage capacity must be sufficient to enable the maximum irrigation demand to be met whenever it occurs.

2. Methods to assess the impact of climate change on water resources and agriculture

The assessment of the physical impacts of climate change on water resources is complex, as impacts include changes in averages of climate parameters and their variability in space and time. One certain impact is the change in water availability due to a likely intensification of water cycle at higher temperatures. The changes in local temperature and precipitation regimes would affect water run-off. Additionally, the quality and quantity of water supply will also be affected and hence its availability for domestic, industrial and agricultural uses. Indications on the impacts of climate change on water resources can be assessed by monitoring watershed hydrological trends. River discharge also provides an indication of the land use/land cover changes in a given watershed.

Climate change causes increased temperatures and greater extremes in rainfall, thus resulting in more frequent drought events. Agriculture is one of the most sensitive sectors to drought, as it depends on water resource availability and land use (Figure 4). This can be highlighted by studying the vulnerability of the Lebanese arid areas and the extent of changes in these areas. The analysis of land use evolution in Lebanon shows a drastic reduction in vegetation cover in the southern region and and the Bekaa Valley (LNAP 2002).

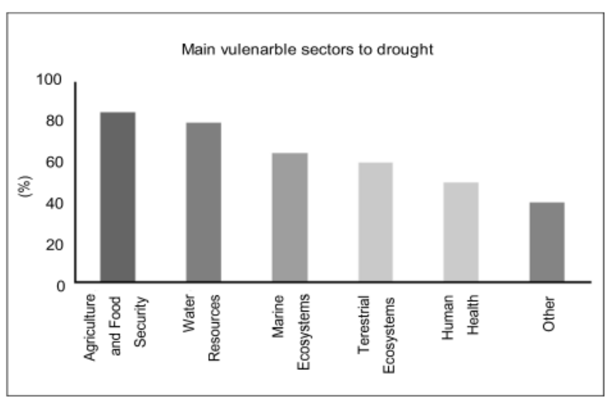

Figure 4. Main vulnerable sectors to drought (after Florin Vladu, UNFCCC 2006).

To assess the climate change following components of the analysis of the rainfall pattern can be useful:

- Number of days in which the rain exceeds the threshold rainfall of the area, on a weekly, 10-day, or monthly basis;

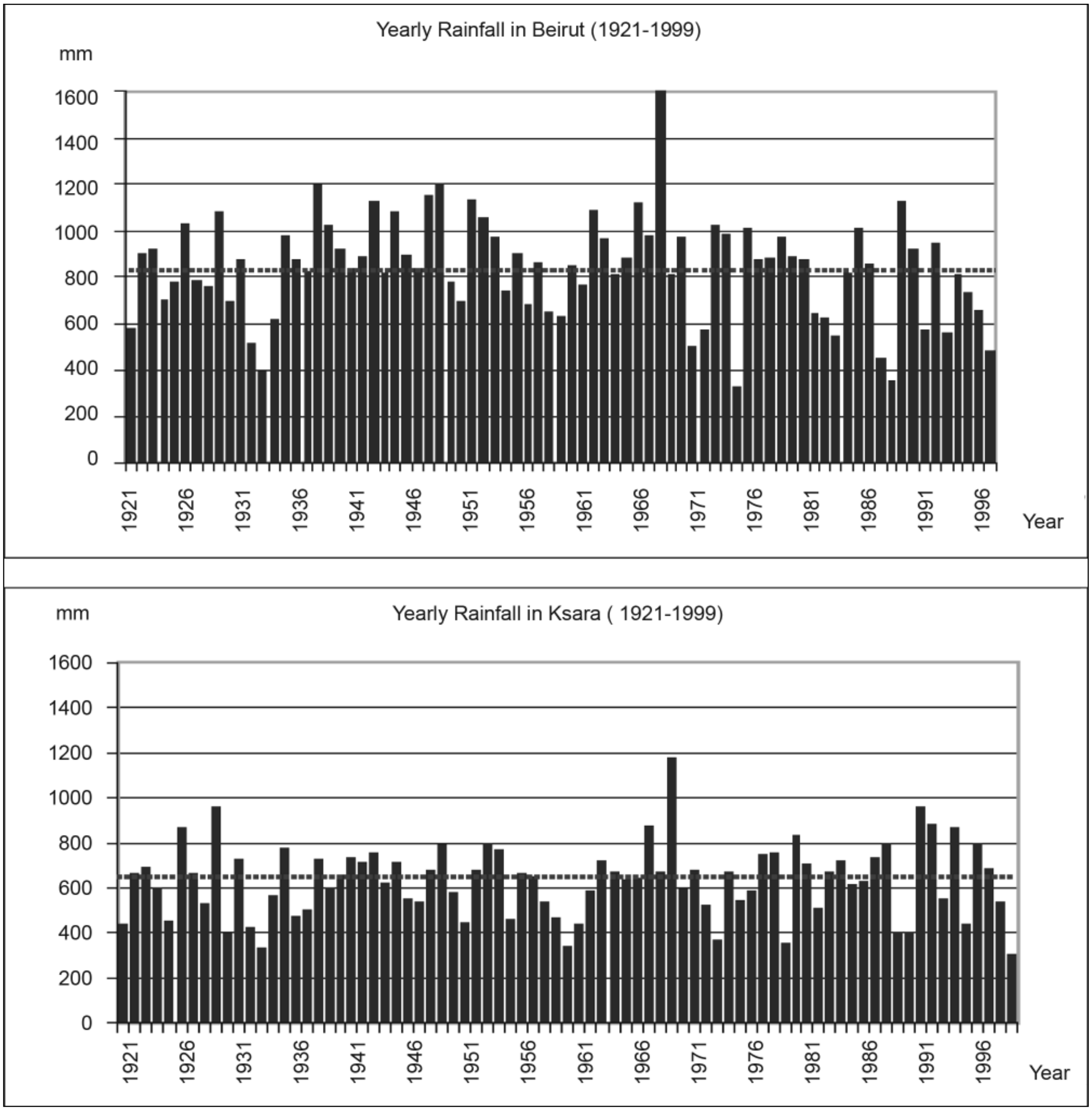

Figure 5. Long-term time series records of rainfall for Beirut and Ksara (Source: Meteo. Archive, Department of Irrigation and Agro-Meteorology, Lebanese Agricultural Research Institute 2002).

- Probability and recurrence at 10-year basis for the mean monthly rainfall;
- Probability and recurrence at 10-year basis for the minimum and maximum monthly rainfall;
- Frequency distribution of rainy days.

An example of rainfall analysis at one year-basis is presented in Figure 5 for two locations in Lebanon, Beirut (coast) and Ksara (inland) as the long-term time series records (1921 to 1999) were accessible only from these two stations. Not much of trend was discernable. However when the decadal rainfall averages were examined over the same period a declining trend was evident for Beirut and a relatively stable pattern for Ksara (Figure 6).

3. Climate change impact analysis

The examination of the climatic events during the last three decades (1970-2000) reveals signs of climate change. There is an increase in the frequency and intensity of droughts, occurrence of unusually devastating floods, a decrease in the period of snow cover on the peaks of high mountains from

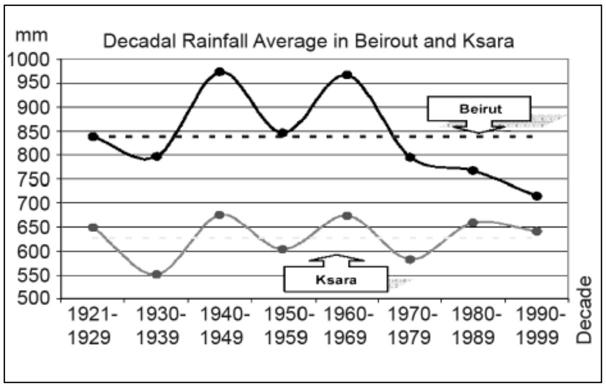

Figure 6. Decadal rainfall average in Beirut (Coast) and Ksara (Inland) (Source: LNAP 2003).

the Mount-Lebanon chain westward to Anti-Lebanon eastward, and a modification of spatial-temporal rainfall distribution (both increase and decrease in different regions simultaneously). The frequency of hot days and heat waves has been increasing, especially in areas where soil moisture deficit was already prevailing. In some areas of the northeast Bekaa Valley, especially those situated at the eastern bank of Assi River (Orontes), an increase in the intensity and frequency of extreme precipitation events was observed, leading to reoccurring floods and massive soil erosion that has increased the level of sedimentation in the river beds and catchment areas.

3.1. Impact on water resources and plans to reduce the impact

Extended drought periods seem to be related to increasing climate variability arising from climate change. Manifestations of water scarcity include, among others, an alarming reduction of both surface and groundwater resources, as is the case in the central plains of the Bekaa Valley where irrigated crop of potatoes is grown and farmers have been digging wells deeper and deeper. The future water availability scenarios there would necessitate diversification of cropping pattern, expansion of sprinkler irrigation, and conjunctive use of surface and groundwater besides improvement in the institutions.

Quantitative estimates of possible climate change impacts on water resources in 2020 suggest that there would be an average and general decrease in water resources of the order of 10 to 15 % in most countries in the Near East Region, including Lebanon. The consequences of this decrease would be:

- A disruption of the watershed flow rates (streams and rivers);
- A decrease in water levels, producing a decrease in the natural outlets for water tables and an increase in their salinity in the coastal areas;
- An overall deterioration of water quality.

The Master Plan of Lebanon's water resources of the Ministry of Energy and Water stated that water storage capacity in the country should be maximized (Comair 2005) in order to cope with the most probable effects of water shortage caused by prolonged drought periods. Moreover, two important measures to adapt to water shortage have been advocated:

- ***Structural adaptation,*** which includes construction of new water structures; rehabilitation of old structures, use of sustainable agricultural techniques, etc;
- ***Non-structural adaptation,*** which includes administrative, political and judicial measures, renewable energy.

Moreover, in its plan to support the irrigation sector, the Lebanese government has promoted an expansion of storage and irrigation infrastructure to potentially service some 177,000 ha of irrigated lands distributed in the large- and medium-scale schemes (MOA/FAO 2000). The government is committed to adopting a number of reforms in the irrigation sector, such as improving water distribution efficiency, upgrading conveyance infrastructures, promoting tariff reform, rehabilitating infrastructure, and enhancing the role of water users' association (Karam and Karaa 2000; Karaa et al. 2004). In addition, it is expected that a national strategy based on the dual approach of demand/supply management will be adopted, with increasing use of tools of advanced technology to enhance the resource management capabilities.

3.2. Impacts on agricultural sector

Agricultural production, including access to food, in many countries of the Near East region is projected to be severely compromised by climate change. The area suitable for agriculture, the length of growing seasons and the crop yield potential, particularly along the margins of semiarid and arid areas, are expected to decrease (FAO 2008). In Lebanon, agriculture vulnerability is estimated to increase with the predicted climate change in terms of the following (FAO 2008):

- Increased demand on water resources;
- Shift of arable area to more arid climate zones;
- Greater erosion leading to a higher level of soil deterioration, and
- Change in land use pattern.

However, potential impacts of climate change on agricultural production will depend not only on climate, but also on the internal dynamics of agricultural systems. In comparison with the more evident biophysical impacts on plants and animals, global impacts of climate change on food production and food security may include marked changes in the geographic distribution of major crop production zones (agro-economic zones) and their associated land-use patterns. Since agriculture in Lebanon is dominated by both rainfed and irrigated agriculture, the impacts of climate change on agriculture could be expected as:

- A decrease in cereal production;
- Negative impacts on citrus, olive, apple and sugar beet production;
- An increase in the water needed to satisfy irrigation requirements of the cultivated crops;
- A shift in growth period and reduction of the whole crop cycles;
- An increase in risks of dry periods at the beginning, middle and end of the annual crop cycle; with negative impacts being more pronounced on wheat and barley during grain formation stages;
- Migration towards the north of the arid zone;
- Extinction of some crops and tree species;
- Appearance of new diseases and pests.

4. Adaptation to climate change

Adaptation, in IPCC terminology, is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. It can include proactive measures such as crop and livelihood diversification, seasonal climate forecasting, community-based disaster risk reduction, famine early warning systems, insurance, water storage, supplementary irrigation and so on. It could also include reactive or ex-post actions, for example, emergency response, disaster recovery, and migration. Recent reviews indicate that the reactive approach is often inefficient and could be particularly unsuccessful in addressing irreversible damages that may result from climate change (Easterling et al. 2004), while proactive practices to adapt to climate variability can develop operational capability to forecast several months in advance the onset of climate-related hazards (Dilley 2000). Mechanisms of proactive adaptation to climate variability are designed to implement anticipatory adaptation measures in agriculture, water resource management, food security, and a number of other sectors.

Many actions that facilitate adaptation to climate change are undertaken to deal with current extreme events such as drought and floods. Often, they are not undertaken as stand-alone measures, but embedded within broader sectoral initiatives such as water resource planning, coastal defense and disaster management planning (IPCC 1997). Examples include adopting reforms in water sector and irrigation sub-sector to improve efficiency in use to address increasing resource scarcity.

Adaptation efforts can be implemented at low cost, but comprehensive estimates of adaptation costs and benefits are currently lacking. A number of adaptation measures are available that can be implemented at low cost or with high benefit-cost ratios, with some common social and environmental externalities (FAO 2008).

High population growth would be associated with a shift towards services and significant wage gaps between agriculture and service sector will trigger rural to urban migration. Priority in water resource allocation would go to more vital sectors such as drinking water, sanitary services and human health, and industry, while water rationing strategy will have to be adopted in urban areas during the periods of peak water shortage. It will therefore be important for the policy maker to understand that the economic impacts of climate change will also be substantial and policy interventions may have to be changed. A different policy environment, for example a reduction in agricultural subsidy support or a more open trading regime, can lead to a different assessment of the impacts of climate change. Table 1 gives a summary of some adaptive measures to climate change with respect to water resources management and agriculture in Lebanon.

5. Concluding remarks

The analysis of the weather conditions indicates several climatic shifts that affect precipitation and

Table 1. Examples of adaptation measures to climate change in water resource and agriculture in Lebanon.

Adaptation in water resource sector	Adaptations in agricultural sector
• Review existing water resources facilities for improvement; • Take structural and non-structural measures to enhance water resources; • Use of recycled water for domestic, industrial and recreational purposes; • Reduce water consumption through economic and administrative measures, such as water pricing; • Ration water during the periods of severe shortage; • Improve watershed management; • Adopt integrated groundwater management; • Integrated surface water management; • Preserve groundwater quality; • Improve efficiency of water supply systems; • Improve efficiency of water treatment systems; • Adopt water conservation (flood utilization & aquifer recharge); • Improve water supply systems; • Improve efficiency of water distribution networks; • Rehabilitate municipal networks; • Equip private wells with water metering devices; • Increase water tariff to recover operation and maintenance costs of water and treated wastewater.	**1- Agricultural water uses:** • Improve water use practices and techniques; • Construct low-cost small reservoirs for irrigation; • Rehabilitate existing small water tanks and reservoirs; • Replace open-channel conveyance systems with pipes; • Improve on-farm water use efficiency; • Promote on-demand irrigation supply and scheduling; • Use of pressurized closed-pipes to prevent evaporation losses; • Use of trickle irrigation systems (surface and sub-surface). **2. Agricultural practices:** • Introduce crops that consume less water; • Develop drought/heat tolerant crops & varieties • Adopt conservation agriculture and new agronomic practices adapted to climate change • Develop integrated farming systems based on water and nutrient recycling; • Practice deficit irrigation. • Grow bio-fuels on marginal lands

consequently the availability of water resources in Lebanon. Climate change is impacting the water resources in terms of i) decreased basic flow of perennial and permanent water courses; ii) decrease in the level of water storage reservoirs due to higher evaporative demand; iii) reduced surface water availability and iv) reduced groundwater reserves. This has led during the last decades to increased occurrence of drought and even flood events have been observed in several areas in northern Bekaa Valley. On the other hand, since urban consumption is predicted to increase because of high population growth and expanded urbanization, it is expected that irrigated agriculture will experience major constraint of water shortage. This would have a considerable negative impact on agricultural production in the country.

Even in the absence of climate change, re-aligning water demand with available supply will require substantial institutional reforms addressing both the water sector proper, as well as other areas influencing water usage among the vital sectors (agriculture, trade, energy, etc). The predicted impacts of climate change would further weaken the whole economic system, and reforms that would make water resource management more environmentally, socially and financially sustainable, would be needed.

The Food and Agricultural Organization of the United Nations (FAO) proposed strategies to support adaptation in water management, including scarcity management strategies, focused on: (i) demand management for efficient allocation and use of water; (ii) protection and conservation of surface water and groundwater resources; (iii) development of alternative water resources; (iv) flood risk mitigation strategies combining watershed management and land planning; and (v) improved governance of water planning, allocation and services. As for the agricultural sector, the

FAO strategy focuses on sustainable interventions to mitigate climate change and to enhance the resilience of rural populations and their livelihoods to climate variability and climate change impacts. In this context, the following specific recommendations are made that apply to Lebanon and other countries in the Near East:

- Develop policies, legislation and activities in natural resource management that can lead to sustainable livelihoods, mitigation and adaptations to climate change.
- Maintain the long-term productive potential of the rangelands;
- Promote the diversification of productive agriculture;
- Adopt climate-resilient production solutions, such as conservation agriculture, drought and flood resistant crop varieties, modification in planting times and other management practices.

On the institutional side, a common and inclusive framework for regular interactions between Lebanese Governmental institutions and local rural communities is urgently needed. Within this developmentcal framework, research is central to bring the experience to better respond to climate change challenges through building capacities at the national and local levels, designing climate proofing interventions, and mobilizing human resources.

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Impact of climate change and variability on diseases of food legumes in the dry areas

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Abstract

Cool-season food legumes are the major crops that provide dietary plant protein to millions of poor people; cash incomes to marginal farmers and sustain cereal-based cropping systems in the dry areas of the world. The productivity, quality and expansion of food legumes are affected by several foliar and soil borne diseases as well as parasitic weeds. The extent of yield losses depends on the interactions of biophysical factors (mainly temperature and moisture), pathogen and the host. Climate change is predicted to affect disease spectrum, particularly the distribution, epidemic development, and appearance of new pathotypes/diseases affecting the crops and disease management practices. For example, Stemphylium blight on lentil was a minor disease but the introduction of lentil in rice-fallows in South Asia has aggravated the problem in the region. Similarly, unusual late rains can cause heavy chickpea pod infection by Ascochyta blight leading to heavy quality losses. Different temperature regimes can affect pathogen virulence - host resistance in Ascochyta-chickpea and Ascochyta-lentil pathosystems. Additionally, temperature fluctuations can also influence the sexual reproduction of *Ascochyta* spp. Increased soil moisture stress and extreme temperatures can affect host resistance. Interactions among soil borne pathogens are being observed in many farmers' fields; mainly the interaction of fungal pathogens with nematodes or with soil inhabiting insect pests that predispose resistant legume varieties to soil born fungal pathogens. Under climate change, research in food legume disease management strategies should focus on refinement of the existing management recommendations and engage in anticipatory research to tackle the emerging pathogens and their interaction with other biophysical factors through multidisciplinary team approach.

Keywords: climate change, disease management, foliar diseases, food legumes, soil borne diseases

1. Introduction

Cool-season food legumes (faba bean, chickpea, lentil, and grass pea) are the major crops grown in the countries of West and South Asia, China, North Africa and East Africa. Lentil, chickpea and faba bean are also becoming an important primary industry in Canada, Australia and USA.

In traditional food legume growing countries, food legumes are the major sources of human food and nutrition, provide animal feed and sustain cereal based production system through improving soil fertility and reducing diseases and weeds.

Although the demand for food legumes is increasing because of the increase in population in developing countries and the importance of these legumes as a healthy food, their production and productivity are very low due to low yielding local landraces, abiotic factors (moisture and temperature stresses), poor agronomic practices, diseases, insect pests, and parasitic weeds.

The major biotic factors affecting food legumes are Ascochyta blights, rust, chocolate spot, botrytis gray mould, Stemphylium blight, anthracnose, wilt/root rots, nematodes, and parasitic weeds (Table 1). The distribution and importance of each disease is either regional or global and limited by environmental factors, methods of dispersion and host distributions. Small scale farmers suffer from crop losses that lead to food insecurity and low incomes during epidemics periods. Some of the diseases not only affect yield but also quality and reduce the marketability of the produce, which is translated to low incomes to farmers.

Table 1. List of major food legume diseases, their estimated yield losses and distribution.

Crop	Disease	Pathogen	Yield loss (%)	Importance
Kabuli chickpea	Ascochyta blight	*Ascochyta rabiei*	Up to 100	Widespread
	Fusarium wilt	*Fusarium oxysporum* f.sp. *cicieris*	10-90	Widespread
	Cyst nematodes	*Heterodera ciceris*	20-100	Eco-regional
Faba bean	Ascochyta blight	*Ascochyta fabae*	30-70	Widespread
	Chocolate spot	*Botrytis fabae*	Up to 100	Widespread
	Rust	*Uromyces viciae- fabae*	27-80	Widespread
	Black root rot	*Fusarium solani*	Up to 100	Eco-regional
Lentil	Ascochyta blight	*Ascochyta lentis*	40-90	Eco-regional
	Stemphylium blight	*Stemphylium botryosum*	23-62	Eco-regional
	Fusarium wilt	*Fusarium oxysporum* f.sp. *lentis*	Up to 100	Widespread
	Anthracnose	*Colletotrichum truncatum*	20-100	Eco-regional
	Rust	*Uromyces fabae*	25-70	Eco-regional

Disease development is determined by the interactions of susceptible host, favourable environment and virulent pathogens. The interactions will lead either to reduced disease intensity or major epidemics. In the changing climate, plant pathogens can quickly develop resistance to fungicides, or adapt to overcome resistance in released and adopted cultivars and can adapt to environmental changes where the level of adaptation depends on the type of pathogens (Garrett et al. 2009). It is well known that environmental factors are one of the key factors for epidemic development in crop production. Climate change brings changes in temperature, atmospheric CO_2 concentrations, and rainfall and causes extreme weather events that affect both food legume production and their pathogens. However, there is little direct evidence available on the effect of climate change on plant diseases including food legume diseases (Diekmann 1992; Evans et al. 2008).

This paper reviews how the predicted climate change in relation to changes in CO_2 levels, temperature and precipitations could impact major diseases of food legumes and their management practices in non-tropical dry lands.

2. Effects of CO_2 on food legume diseases

Rise in atmospheric CO_2 levels would affect the physiology, morphology and biomass of crops (Reunion 2003). As a result C3 crops are expected to accumulate more biomass (Challinor et al. 2009) and this should also apply to food legumes.

The increase in canopy size changes the microclimate and exposes high amount of host tissue to be infected during the epidemic development (Pangga et al. 2004). Necrotrophic foliar pathogens like Ascochyta blights, Stemphylium blight and Botrytis gray mould can be a serious threat in food legumes if the conditions favour high canopy density. The favourable micro-climate environment created by elevated CO_2 can lead to high reproduction rates of polycyclic diseases that will generate highly virulent pathotypes that can affect the existing resistant food legume cultivars. Some studies showed that elevated CO_2 levels increased shoot and nodule growth (Nasser et al. 2008) in lentil and in alfalfa (Fischinger et al. 2009) that may in turn result in high canopy growth which alters microclimates favourable for foliar disease development. In addition to increased crop canopy cover, elevated CO_2 can increase root biomass that can be attacked by soil borne pathogens. High root exudates will affect both pathogens and antagonistic micro-organisms (Ghini et al. 2008). In *Colletotrichum-Stylosanthes* pathosystem, the aggressiveness of the pathogen was increased under elevated CO_2 levels (Chakraborty and Datta 2003; Gregory et al. 2009).

Food legumes such as faba bean and lentil suffer huge yield losses due to the holo-parasitic weeds (*Orobanche* spp.) in the Mediterranean and Nile Valley countries. In a study on the interaction effects of the parasitic weed *Orobanche minor* and its host *Trifolium repens*, Heather and Press (1998) found that an increased CO_2 level affected host growth but not of the parasitic weed.

Increased CO_2 levels in the atmosphere will lead to low levels of decomposition of crop residues and as a result, some soil borne pathogens would multiply on the crop residues and start early infection on the crop. Moreover, the un-decomposed straw of food legumes can serve as a breeding ground for stubble borne pathogens with a known sexual reproduction that provides the primary sources of inoculum to start an early epidemic development. The role of un-decomposed pulse residue in sexual reproduction in developing countries may however be not so high as the straw is taken away as a valuable animal feed by small scale farmers. But, there will be a serious problem in conservation agriculture, where residues remain on the ground and food legumes are an important component of the cropping system. Reunion et al. (1994) reported that the incidence of *Rhizoctonia solani* on cotton increased with increased CO_2 concentration. If food legumes are introduced in cotton based cropping system, the same pathogen can become a serious problem for the other crops in the rotation besides enhancing the level of inoculum for the succeeding cotton crop.

3. Effects of temperature on food legume diseases

Temperature is one of the key environmental variables affecting disease development. Food legume pathogens have varying ranges of temperatures requirements for disease initiation, epidemic development, survival and sexual reproduction (Table 2). In the Mediterranean environment, for example, lentil wilt usually appears during the late vegetative and early flowering stages of the crop in the months of April when the temperatures are rising. However, in East African highlands and South Asia wilt appears during all growth stages of the crop since the temperature for disease development is favourable throughout the season.

Besides affecting disease development, temperature also affects the genetic resistance of the host crops and the virulence/aggressiveness of the pathogens. Landa et al. (2006) found that with an increase in 3°C the Fusarium-wilt resistant chickpea variety become susceptible and the races of *Fusarium oxysporum f. sp.* ciceri showed cross over interactions with temperature for their virulence on different chickpea varieties. The interaction of temperature with Fusarium-wilt resistant cultivars has an implication in cultivar development and other disease management practices like sowing dates. If the cropping season is getting warmer, there is a need to change the sowing date of the crop or breeders have to develop chickpea cultivars with resistance genes that are not affected by changing temperature during the cropping season.

In lupine-anthracnose pathosystem, Thomas et al. (2008) found that the resistant variety 'Wonga' became susceptible when the temperature increased to 26°C. Preliminary studies (Ahmed u*npublished data*) on the effect of temperatures on host resistance and pathogen virulence in the Ascochyta-lentil and Ascochyta –chickpea pathosystems showed that both the virulence of the pathogens and the resistance of the cultivars showed varying levels of interactions with different levels of temperatures. In lentil-Ascochyta system, the virulence of the isolates and susceptibility of the cultivars was very high at lower than higher temperatures (Figure 1a &b).

Similar trends were observed in the chickpea-Ascochyta pathosystem where the virulence and susceptibility of the pathogen and the host were affected by varying levels of temperatures (Figure 2a &b). For example, the most virulent Pathtype-4 was affecting genotypes at all ranges of temperature studied.

Farmers in the Mediterranean region delay sowing of food legumes as an escape mechanism from the parasitic *weed Orobanche* spp. Researchers have released some faba bean resistant cultivars but the impact of temperature on the resistance is not well established. However, in sunflower,

Table 2. Temperature and humidity requirements of selected food legumes diseases.

Crop	Disease	Causal pathogen	Temperature range (°C)	Humidity [1]
Lentil	Ascochyta blight	*Ascochyta lentis*	10-22	High
	Rust	*Uromyces viciae-fabae*	20-22	High
	Anthracnose	*Colletotrichum truncatum*	15-20	High
	Stemphylium blight	*Stemphylium botryosum*	5-30	High
	Botrytis grey mould	*Botrytis cinerea*	18-22	High
	Fusarium wilt	*Fusarium oxysporum* f.sp. *lentis*	20-25	Low
Chickpea	Ascochyta blight	*Ascochyta rabiei*	15-25	High
	Fusarium wilt	*Fusarium oxysporum* f.sp. *ciceris*	20-30	Low
	Botrytis grey mould	*Botrytis cinerea*	15-25	High
	Cyst nematodes	*Heterodera ciceri*	10-20	Low
Faba bean	Chocolate spot	*Botrytis fabae*	15-22	High
	Rust	*Uromyces viciae-fabae*	20-22	High
	Ascochyta blight	*Ascochyta fabae*	18-22	High

[1] High => 70% humidity; and Low= <70% humidity

resistance to parasitic weeds is known to be temperature dependent. Eizenberg et al. (2003) found that at high temperature (29°C), there were more tubercles degeneration and death of *O. cumana* on resistant sunflower cultivar 'Ambar' compared to low temperature.

Other than affecting disease development host resistance and pathogen virulence/aggressiveness, temperature can favours the development of minor diseases like powdery mildew and dry root rot on food legumes under hot and dry conditions. Powdery mildew could be a serious problem when food legume production is extended to the heat stressed areas using irrigation.

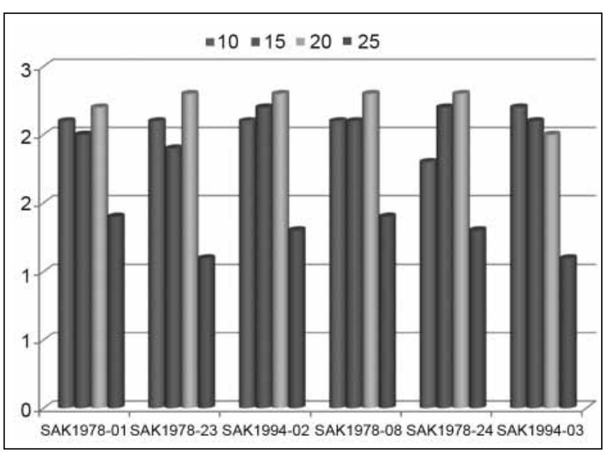

Figure 1a. Effect of temperature (°C) on mean virulence of isolates of *Ascochyta lentis* on six lentil genotypes.

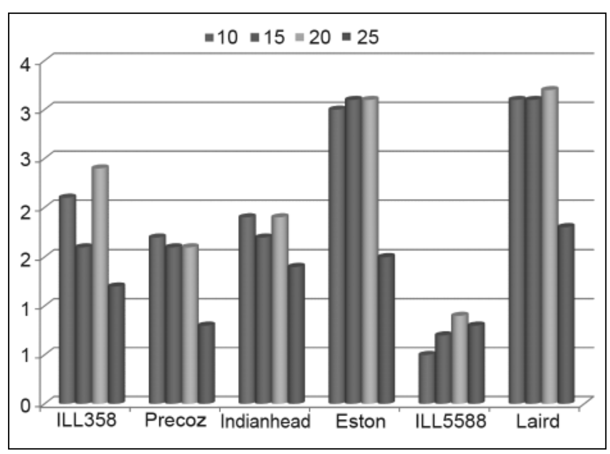

Figure 1b. Effect of temperature (°C) on mean disease severity on six lentil genotypes inoculated with *Ascochyta lentis.*

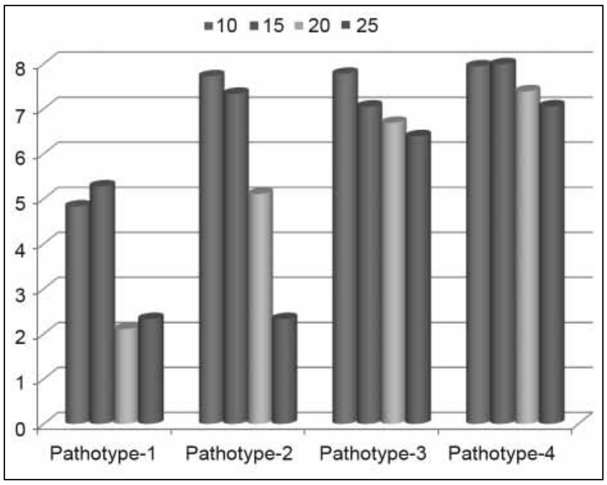

Figure 2a. Effect of temperature (°C) on mean virulence of different *Ascochyta rabiei* pathotypes on six chickpea genotypes.

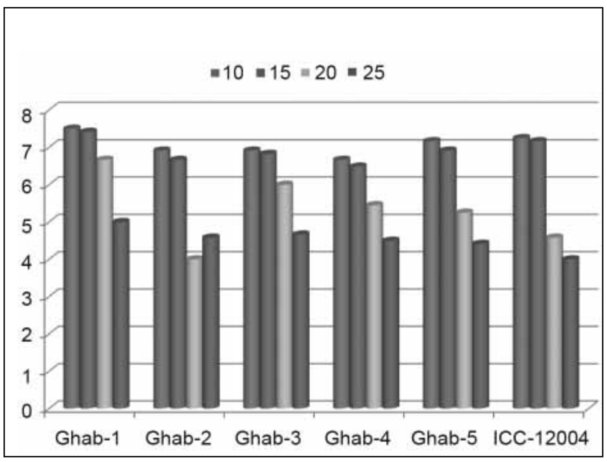

Figure 2b. Effect of temperature (°C) on mean disease severity on six chickpea genotypes inoculated with *Ascochyta rabiei* pathotypes.

4. Effects of precipitation on food legume diseases

Rainfall affects both crop and disease development in food legume production systems. Most of the key foliar diseases and some soil borne pathogens are favoured by increased rainfall. Increased soil moisture also favours root rotting pathogens like *R. solani, Pythium* spp., *Phytophthora* sp. In areas where rainfall is decreasing due to climate change, fusarium wilt, dry root rots, nematodes and parasitic weeds will become problematic for the cool-season food legumes.

Untimely rainfall caused by extreme weather events can cause severe yield and quality losses to major food legume crops. In the 1997/98 cropping season, untimely rainfall in October-November favoured lentil rust epidemics and devastated late planted landraces leading to total yield and straw losses in Ethiopia (Negussie et al. 2005). During the rust epidemic season, only one rust resistant lentil cultivar, 'Adaa' (FLIP-86-14L) grown by one farmer remained free, which for that reason was later widely adopted by small holder farmers in the central highlands of Ethiopia. The late rain in May 2007 in Syria resulted in severe chickpea pod infection by Ascochyta blight (Mathew et al. 2007). The severity of pod infection was high because the resistant cultivars grown by farmers were not resistant at the stage of physiological maturity.

5. Effects of climate change on pathogen reproduction

The major evolutionary forces that play a great role in shaping the population structure of food legume disease causing pathogens are mutation, migration, genetic drift, selection and recombination (Linde 2010). These forces and their interactions are very important for pathogens to adapt to changes in climate. Plant pathogens can exploit the different stresses imposed by the changing climate and management practices to generate new variants that adapt to the changes. For example, some pathogens like *Fusarium oxysporum* can stimulate the activity of retrotransposons and are able to generate variability in the pathogen populations. Sexual reproduction in *Didymella* spp. affecting food legumes requires low temperature and sufficient moisture under field conditions (Pande et al. 2005). The sexual spores can travel long distances by wind and initiate disease in the field. With increased frequency of storms and cyclones the spread will increase and necessitate adoption of some of the control practices of Ascochyta blights like fungicide seed treatment and crop rotation in areas where it was not necessary before.

6. Interactions of food legume pathogens with abiotic factors

Due to climate change and variability food legume growers are experiencing frequent droughts. Drought stress is favourable for the development of some diseases. Moreover drought predisposes resistant varieties to be easily attacked by pathogens which are not a problem during normal growing season. For example in 2007/08 there was a serious drought in Syria and Fusarium-wilt resistant lentil cultivars like Idleb-3 and Idleb-4 showed high plant mortality (Figure 3).

7. Changes in cropping systems and food legume diseases

Increased disease damage in quantity and quality in food legumes could arise from changes in production systems, pathogen population and growing of the crops in new areas mainly under warm and more humid climatic conditions. Different strategies are being used to increase land productivity and adapt to or mitigate climate change in crop production. The changes in cropping systems result in minor diseases becoming a major yield limiting constraint in food legumes.

The introduction of lentil in rice-fallow system in South Asia has increased the problem of Stemphylium blight and collar root rots. Collar root rot (*Sclerotium rolfsii*) multiplies as saprophyte on rice straw and affects emerging seedlings, causing huge yield losses. In Australia, the production of faba bean under zero tillage systems has favoured the development of Cercospora leaf spot which is a minor disease on faba bean in different countries (Kimber et al. 2007). In some counties, supplementary irrigation is becoming more popular to boost production of food legumes and as a result, minor diseases like powdery mildew will become problematic.

8. Food legume diseases and their management in changing climate

It is believed that the existing plant disease management practices need some degree of adjustments in the changing climate scenarios (Garret et al. 2006). Many disease management options used by small and large scale farmers growing food legumes include host plant resistance, fungicide applications, adjusting sowing dates, manipulating plant population and crop rotations. National research systems and the International Centre for Agricultural Research in the Dry Areas (ICARDA) are allocating sizable amount of resources to develop high yielding and disease resistant cultivars and integrated disease management practices for the non-tropical dry areas. Farmers, who can afford, manage Ascochyta blights using fungicides as foliar application and seed treatment. Under climate change scenarios, there will be changes in

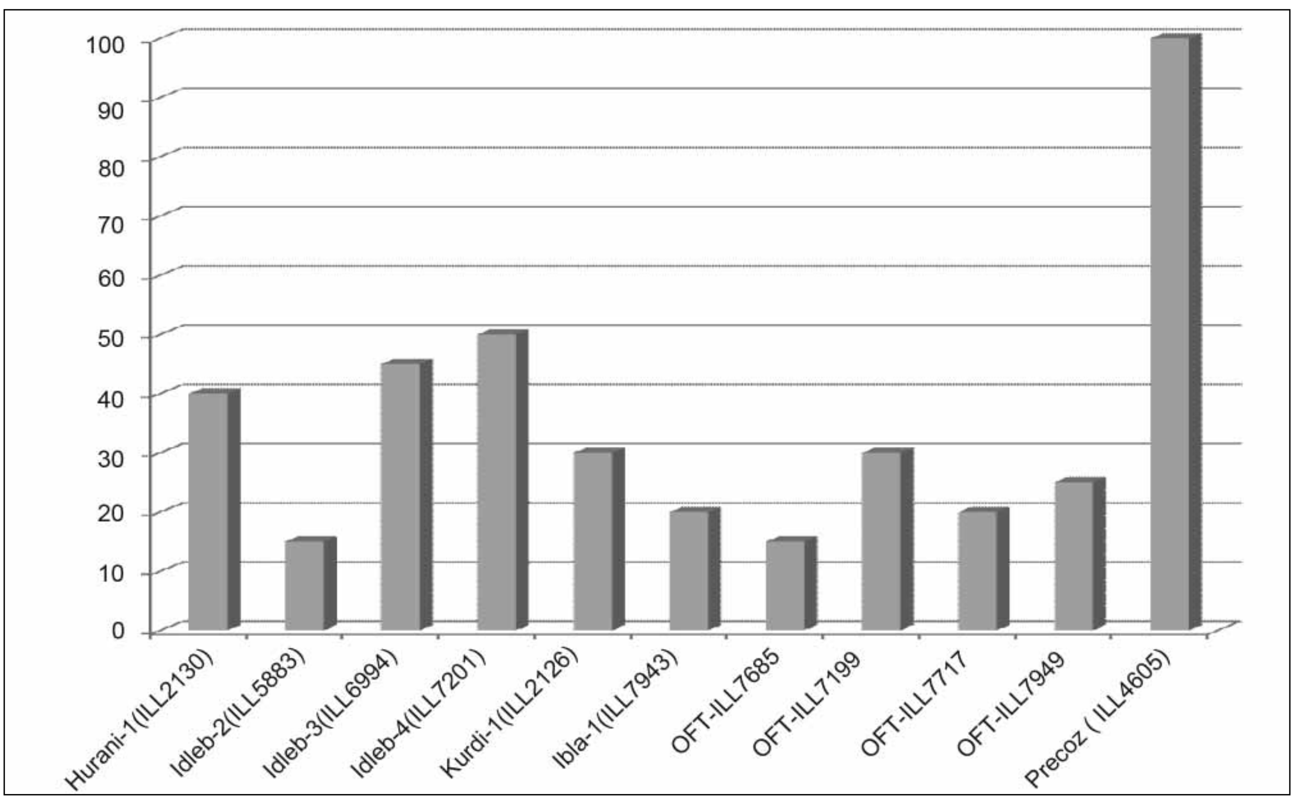

Figure 3. Mean percent Fusarium wilt mortality of lentil genotypes under low rain fall condition, 2007/08 cropping season, Tel Hadya, Syria.

canopy size and host physiology that will facilitate greater chances of overcoming host plant resistance by pathogens that can develop new virulent/ aggressive variants through rapid disease cycles leading to the production of enormous number of pathogen propagules. In areas where there is high precipitation, famers may be obliged to spray fungicides frequently. For example, one to two sprays are recommended at vegetative and flowing stages of winter-planted chickpea to manage Ascochyta blight in Syria (Akem et al. 2004). If precipitation increases due to unusual rains, farmers will have to increase fungicide applications or shift their planting to spring, which will force them to lose the yield advantage they are getting from winter chickpea.

Host plant resistance can be broken down by changing climate due to development of new pathogen variants. Therefore, there is a need to change and fine tune the existing disease management strategies. If some parts of the region where food legumes are important are getting drier, the importance of foliar diseases like Ascochyta blights will be less problematic and other diseases mainly soil born fungal pathogens and parasitic weeds will become economically important. Hence there is a need to develop new control practices for the new diseases and parasitic weeds in those areas.

Climate change could bring shifts of micro-organism populations, changing the balance between the beneficial organisms and pathogens. The option of managing food legume diseases using biological control will be affected by changes in temperature, rain fall and the frequency of extreme weather events. Hence, the development of bio-pesticides should consider the future reality of climate changes.

9. Conclusions

Cool season food legumes will remain crucial for millions of people in rural and urban areas in providing food and sustaining cereal cropping system. When conditions become drier in some parts of the world, food legumes generally provide an alternative crop choice. Their production is also expected to expand in wetter areas because of the increasing realization of their role in improving soil fertility and structure. Climate change will bring new diseases and also affect the importance and distribution of existing ones. Greater movement of human and genetic resources will produce new types of interactions as pathogens, are introduced to new areas and they may hybridize/ or become major problems. This is very important for seed borne pathogen like *Ascochyta* spp., a key pathogen causing disease in food legumes.

Most of the studies in the past have been done under controlled conditions on the effect of single weather variables like temperature, moisture on the host, the pathogen and their interaction (Coakley et al. 1999). There is a need to undertake field studies in an integrated manner investigating the combined effects of climate change scenarios.

Management options developed and used by farmers (cultural practices, host resistance and pesticide applications) should be revisited based on the changing environments. Emphasis should be given to study the consequences of new cropping systems designed to mitigate or adapt to climate change since food legumes will be a key components of many cropping systems in dry areas. Testing and adopt of conservation agriculture being done in Central Asia and West Asia should include critical evaluation of diseases in the food legumes being introduced to sustain the cropping practices.

Prediction of the future effects of global warming showed negative effects on crop growth and yield at low latitudes and some positive effects in the high latitudes. If food legumes are to expand in the North, diseases that are favoured by high rain fall, mainly foliar diseases, will have to be considered. In the low latitudes there will be change in importance of diseases towards soil-borne pathogens and parasitic weeds, which will need more attention.

Food legumes are subjected to many biotic and abiotic stresses. Modelling should be done to include key factors like diseases and parasitic weeds affecting the productivity of crops. Models can simulate global climate change scenarios at different levels of disease severity with the aim to estimate yield and to develop control options that will help in decision making process. Multidisciplinary team of experts should participate to combat food legume diseases in changing climate.

Efforts have been made by the Consultative Groups on International Agricultural Research

(CGIAR) through the System-wide Program on Integrated Pest Management (SP-IPM) in which many centres are participating. The SP-IPM is focusing on climate change, food; feed and environmental safety, agro-ecosystem resilience, and capacity building. SP-IPM expects to respond to threats resulting from climate change by carrying out collaborative research and surveillance to evaluate the changes in cropping systems and production practices affected by it.

International, regional and multidisciplinary collaboration are very important in dealing with climate change and its impact on diseases of crops. This is critical to cool-season food legumes, which are critical for the well being of millions of poor farmers and urban dwellers in West Asia, North and East Africa, and south and south East Asia. Such types of international collaborations have been formed for food legumes. The first one is the International Food Legume Research Conference being held every four years since1986. The second one the international workshop on Ascochyta blights of cool-season food legumes being organized every two years since 2006. These two forums will bring scientists, donors and policy makers together to work on research for development on food legume diseases in relation to climate change.

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Implications of climate change on insects: the case of cereal and legume crops in North Africa, West and Central Asia

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Abstract

The expected decrease in precipitations by about 25% and increase in temperatures by 3-4°C by 2099 in Central and West Asia and North Africa (CWANA) would have great impact on insect pests and their natural enemies. Warmer environments would favor rapid insect development giving rise to more insect generations per year and thus higher sizes of population of pests, which in turn would cause more damage to crops and also accelerate development of biotypes. Higher temperatures would favor the geographical distribution (both in terms of latitude and altitude) of the pests within the CWANA region and beyond. The climate changes could also create favorable environmental conditions for some secondary insects to become key pests. Surveys must be continuously conducted in the region to monitor changes in the population structure of insect pests and their natural enemies in response to these climate changes. Warm and dry climate would require the use of appropriate management options (resistant cultivars possessing stable genes under higher temperature regimes, new planting dates, new biopesticide formulations allowing a better efficacy and persistence, and promotion of adapted natural enemies to these new climatic conditions). The implications for some major pests are highlighted.

Keywords: biopesticides, biotypes, cereals, climate change, insects, legumes.

1. Introduction

Cereal and food legume production in Central and West Asia and North Africa (CWANA) is severely affected by a range of insect pests. Losses inflicted by the pests, which vary from region to region depending on climatic conditions, are estimated to be on an average 30-50% (Lhaloui et al. 1992; El Bouhssini et al. 2008; Trissi et al. 2006). Integrated management options for most of the key pests have been developed. These are based on an integration of genetic control (El Bouhssini et al. 1988, 1996, 2008, 2009; Lhaloui et al. 2001a, 2001b; Nsarellah et al. 2003; Malhotra et al. 2007), biological control (El Bouhssini et al. 2004; Edgington et al. 2007; Parker et al. 2003; Trissi et al. 2006) and cultural practices (Ryan et al. 1996; Lhaloui et al. 1992; El Bouhssini et al. 2008).

Recognition of climate change is now becoming an international reality. All the models predict that the region of North Africa and most of West and Central Asia will be the severely hit by climate change. Temperatures are expected to increase by 3-4°C and rainfall to decrease by 25-30% by 2099 (IPCC 2007) and the change would have negative consequences on all components of the ecosystem including plants, insects and pathogens.

2. More crop damage and losses

Unfavorable climatic conditions with less rain would not favor good plant growth and development, resulting in weak plants that would therefore be more affected by insects infestation, and thus suffering more yield losses.

High temperature regimes would favor insects attack early during the season, when plants are still young and more susceptible. The Sunn pest (*Eurygaster integriceps* Puton), for instance, usually starts migrating to cereal fields when the average temperature is about 13°C (Javahery 1995), which generally coincides with the end of tillering stage of the wheat crop in West Asia. An increase of temperature by few degrees would trigger the adults' migration to cereal fields a few weeks earlier than usual, which might coincide with the beginning of tillering stage of the crop, causing more damage by killing tillers.

If adults were to emerge earlier than usual for pests such as the chickpea leaf miner (*Liriomyza cicerina* R.), female oviposition would coincide with young plants, and thus the larvae would cause more damage to the crop. Generally, winter planting has been recommended to reduce the effects of chickpea leaf miner infestation (El Bouhssini et al. 2008), but this option would not be possible with the expected impact of climate change.

3. Secondary insects to become key pests

Changes in temperature and rainfall could create a favorable environment for the secondary pests or newly introduced ones to become key pests and spread widely. The cereal leaf miner (*Syringoparis temperatella* Led.) used to be a secondary pest in CWANA with an infestation rate not exceeding 5%. Recently, with the recurrent drought experienced in the region, this insect has become an economic pest of wheat and barley south of Jordan, north-western Iraq and eastern Syria (ICARDA 2006). The barley stem gal midge (*Mayetiola hordei* Keiffer) has been an important pest of barley in North Africa. Starting in 2009, however, there has been an outbreak of this pest on barley in Syria as well, which could be attributed to higher winter temperatures. Usually between November and January, there are several days where the temperature is below zero in Syria, thus partly killing the insect population. However, in the 2009/10 growing season there was no single day during November to January when the temperature fell below zero, thus allowing one full generation of the barley stem gall midge to fully develop. The mild temperatures after January also allowed a second generation to develop, thus causing a lot of damage to barley in Syria.

4. Loss of genetic biodiversity

The recurrent droughts in the region combined with overgrazing would speed up the loss of genetic resources of crops and their wild relatives, which are essential for developing cultivars resistant to various stresses including insect pests. This loss can deprive the crop improvement programs of the new and effective sources of resistance to major insects of cereals and legumes. Targeted collections are needed to secure more genetic resources for their conservation in genebanks. Also *in situ* conservation approaches could contribute to promoting the dynamic conservation of agrobiodiversity for better adaptation to climate change. The International Center for Agricultural Research in the Dry Areas (ICARDA) holds in its genebank more than 134,000 accessions, made up essentially of local populations, and wild relatives of cereal and legume crops. Efforts are ongoing to evaluate these accessions for resistance to the key pests in the region, and several sources of resistance to Russian Wheat Aphid, Hessian Fly, Sunn pest at the vegetative stage, Sitona and chickpea leaf miner have been identified. Crosses with these sources of resistance for breeding purposes and for genetic studies are being made.

5. Effect on expression of host resistance to pests

High temperature regimes affect the expression of resistance genes. Most of the Hessian fly (*Mayetiola destructor* Say) resistance genes are fully expressed at about 20°C. However, some genes lose about 30% and 50% of their effectiveness under temperature regimes of 24°C and 28°C, respectively. The gene expression also varies depending on the growth habit (winter, spring) in wheat (El Bouhssini et al. 1999). The evaluation of germplasm for resistance to insects should be carried out under different temperature regimes to be able to identify genes that are stable under higher temperatures for use in the breeding programs to develop resistant cultivars.

6. Increase in the number of insect generations

High temperature regimes would accelerate insect development; shorten their life cycle and thus lead to a higher number of generations per year. A high number of generations of aphids would cause more damage, either through direct feeding or through viral transmission. Insects such as Hessian fly on wheat and chickpea leaf miner, which usually have two generations per year, could develop a third generation under higher temperature regimes, which would inflict more damage to the crops. An increase in the number of generations would also favor the development of more biotypes of the pests. Once a mutation carrying a virulent allele is created in the insect population, its frequency should increase rapidly in nature because of the high number of generations. The problem might be more pronounced for insects with parthenogenetic or asexual reproduction such as aphids;

females give direct birth to individuals carrying the virulent mutation and consequently should speed up the development of virulent biotypes in nature, thus shortening the life span of the resistant cultivars. Thus, appropriate gene deployment strategies along with other management options need to be used.

7. Range expansion of existing pests

Looking at the minimum and maximum temperatures for development of cereal and legume insect pests in CWANA, an increase in temperature by a few degrees would favor the development of some of the species within and even outside the region. Hessian fly, for example, in Central Asia has been causing economic damage only in north Kazakhstan. Because of climate change, it is expected that this insect could spread throughout Kazakhstan and other countries of Central Asia. Hessian fly used to be limited to North Africa, South Europe and North America (USA); it has now been reported to be moving North of Europe, and it is already now in France.

8. Reduction in the effectiveness of pesticides

High temperatures have been found to affect the persistence of pesticides (Bailey 2004). Thus, current pesticides might become less effective against insect pests, and there might be need to use higher doses of chemicals to reach a good level of efficacy. This unfortunately would have negative effects on the environment, natural enemies of the pest, and the population structure of insects (secondary becoming key pests, development of resistance to pesticides, etc). The use of biopesticides based on entomopathogenic fungi would require the selection of thermo-tolerant fungal isolates and appropriate formulations (Kouvelis et al. 2008).

9. Conclusion

The following measures are necessary to cope with the effect of climate change on insect pests and their control:

- Continuous monitoring of insect pests and their natural enemies;
- Development of prediction models for the outbreak of major pests
- Identification of resistance genes stable under high temperature regimes;
- Use of appropriate gene deployment strategies;
- Development of appropriate IPM options (new planting dates, new formulations of pesticides/ bio-pesticides, adapted bio-control agents for hotter and drier environmental conditions, etc).

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Climate change impact on weeds

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Abstract

The impact of climate change on single species and ecosystems are likely to be complex. However, opposed to crops, weeds are troublesome invaders, ecological opportunists and resilient plants with a far more genetic diversity. Weed populations include individuals with the ability to adapt and flourish in different types of habitats. Weeds benefit far more than crop plants from higher levels of CO_2 and the implications of this for agriculture and public health are grave. Weeds are able to respond rapidly to disturbances giving them a competitive advantage over the less aggressive species, most crops. With increasing certainty that the Earth's climate is changing and that significant warming is inevitable regardless of future emission reductions, it has become progressively more important to identify potential vulnerabilities and adaptive responses in managed ecosystems. Enhancing CO_2 levels, not only increases growth rates of many weeds, but may lead to changes in their chemical composition. Interactions between climate change and crop management in any agroecosystems may turn some currently benign species into invasive species, thus leading to changes in weed composition. As climatic zones shift, weeds that are capable of rapid dispersal and establishment have the potential to invade new areas and increase their range. Developing techniques for managing the increasing burden of the upcoming weed situations will be essential.

Keywords: climate change, crop-weed competition, elevated CO_2 level effects, invasive species.

1. Introduction

The projected increases in the concentrations of CO_2 in the Earth's atmosphere lead to concern over possible impacts on agricultural pests. All pests would be affected by the global warming and consequent changes in precipitation, wind patterns, and frequencies of extreme weather events which may accompany the "greenhouse effect." However, only weeds are likely to respond directly to the increasing CO_2 concentration.

Weeds are undesired plants that interfere with human welfare. Man considers weeds as troublesome invaders and ecological opportunists. Weeds are resilient plants that have adapted to every means of exterminating them, even turning the treatments to their own advantage. Hoeing or plowing perennial weeds for example, may destroy the plant's aboveground growth but leaves the soil full of cut pieces of underground propagules, each of which may sprout a new plant.

Crops and weeds embody opposed genetic strategies. Over the centuries, breeders have deliberately bred the genetic diversity out of crop plants. Creating crop populations composed of clones or near clones was an essential step in achieving higher yields and the sort of uniform growth that makes large-scale, mechanized cultivation and harvesting possible. Because weed genomes were not so-interrupted, weed populations include individuals with the ability to flourish in various types of habitats. For this reason, weed plants behave as successful opportunists and can cope with the wide range of climatic changes, control measures or environmental stresses. Populations that lack the necessary genetic diversity are environmentally benign. Accordingly, any change in the environment will, in effect, favor weed communities, as there will always be a weedy plant poised genetically to benefit from such changes.

The characteristic of weeds to be able to respond rapidly to disturbances such as climate change, may give them a competitive advantage over less aggressive species. Climate change, as well as the interactions between climate change and other processes (such as changes to land use), may also turn some currently benign species (both native and non-native) into invasive species and may lead to 'sleeper' weeds becoming more actively weedy, and have the potential to spread widely and have a major impact on agriculture.

Limited empirical data exist on the impact of climate change on weeds. Weeds are likely to be the most successful at adapting to a warmer climate, as they are aggressive primary colonizers. Weeds are well-adapted to respond to landscape disturbance caused by the increased frequency and intensity of extreme weather events that will accompany a warmer climate. Events such as cyclones, flooding, drought and fires will become more common and weeds will be the first to gain a stronghold after these events.

2. Competition

Any direct or indirect consequences of the CO_2 increase that differentially affect the growth or fitness of weeds and crops will alter weed-crop competitive interactions, sometimes damaging and sometimes benefiting the crop (Patterson 1995).

Elevated levels of CO_2 have been utilized in confined glasshouses to increase productivity in a process known as CO_2 fertilization. Photosynthetic rates respond to increasing levels of CO_2 but then level off at higher concentrations (around 700 m mol/mol or greater, depending upon species and other factors). To date, for all weed-crop competition studies where the photosynthetic pathway is the same, weed growth is favored as CO_2 is increased over crop plants (Ziska and George 2004).

Higher CO_2 will stimulate photosynthesis and growth in C_3 weeds and reduce stomatal aperture and increase water use efficiency in both C_3 and C_4 weeds. In monoculture, Ziska (2001) found that elevated CO_2 significantly stimulated leaf photosynthetic rate, leaf area, and aboveground dry weight of common cocklebur (*Xanthium strumarium*) more than that of sorghum (*Sorghum bicolor*), and the vegetative growth, competition, and potential yield of the C_4 crops could be reduced by co-occurring C_3 weeds as atmospheric carbon dioxide increased.

Crop–weed interactions vary significantly by region; consequently, depending on temperature, precipitation, soil etc., C_3 and C_4 crops may interact with C_3 and C_4 weeds. Patterson (1993) indicated that the relative increase in plant biomass in weeds and crops at doubling of CO_2 concentration might reach over 2.4 X in C_3 compared to 1.5 X in C_4, with weeds gaining more growth than crops in both categories.

Weeds compete with crop plants for moisture, nutrients and light. Many weeds are highly efficient at using available soil water. For example, cocklebur (*Xanthium strumarium*) can extract moisture four to five feet around each plant, and crabgrass (*Digitaria* spp.) two to three feet around each plant. Both species are capable of drawing moisture from up to four feet deep in the soil. When rainfall is limited, effects of weed competition on crop yield may be even greater than during years of adequate moisture. The combined effects of drought and weed competition limit yield potential considerably.

Water-use efficiency (WUE) (ratio of CO_2 uptake to evapotranspiration) will increase under higher CO_2 conditions. This increase is caused more by increased photosynthesis than it is by a reduction of water loss through partially closed stomata.Any factor which increases environmental stress on crops may make them more vulnerable to attack by insects and plant pathogens and less competitive with weeds (Patterson 1995), as WUE for many weeds is much higher than many crops. The percent increase in water use efficiency for the crops: sunflower (C_3) 55%, corn (C_4) 54%, soybean (C_3) 48% and for the weeds: *Ambrosia artemisiifolia* (C_3) 128%, *Abutilon theofrasti* (C_3) 87%, *Datura stramonium* (C_3) 84%, and *Amaranthus retroflexus* (C_4) 76%. Under imposed drought, Patterson (1986) found that CO_2 enrichment reduced the effects of water stress and significantly increased leaf area and total dry weight of the three C_4 grasses; *Echinochloa crus-galli*, *Eleusine indica*, and *Digitaria ciliaris* and soybean. He concluded that CO_2 enrichment can increase the growth of both C_3 and C_4 plants under water stress. But, growth stimulation can be expected to be greater in C_3 plants.

Climate change was shown to reduce plant available nitrogen through elevated CO_2 (Williams et al. 2001; Zhang et al. 2005). The carbon: nitrogen ratio of leaves is usually increased under CO_2 enrichment. Availability of nutrients such as Nitrogen and Phosphorus appears to quickly become limiting, even when carbon availability is removed as a constraint, on plant growth when ambient CO_2 concentrations are sufficiently increased (Hall and

Allen Jr. 1993). C_4 plants have higher nutrient use efficiencies than C_3 grasses, and reduced nitrogen availability has been shown to benefit C_4 plants over C_3 plants in tallgrass prairie (Bleier and Jackson 2007). Changes that increase the dominance of C_4 plant species would change the plant community structure and may change ecosystem function, such as nutrient cycling, and have specific consequences for wildlife habitat (nutritional quality of forage and habitat requirements).

Many experiments characterize the effects of elevated ambient CO_2 on comparative physiology and growth. Respiration, and photosynthate composition, concentration, and translocation may be affected. Warming temperatures and elevated levels of CO_2 resulted not only in increased weed growth rates, size and pollen production, but also in a change in the plants' chemical composition. *Chenopodium album* grew much taller and produced more pollen under warmer and higher CO_2 concentrations (Ziska 2001; Ziska and George 2004). The Ragweed (*Ambrosia artemissiifolia*) grown in 600 ppm CO_2 produced twice as much pollen as plants grown in an atmosphere with 370 ppm. In addition, the pollen contained more of an allergy-provoking protein and aggravated public health problems. Poison ivy (*Toxicodendron radicans*) grew more vigorously at higher levels of CO_2 and produced a more virulent form of urushiol, the oil in its tissue that provokes a rash. The cheatgrass (*Bromus tectorum*) grown under higher levels of CO_2 produced more biomass with more carbon in its tissues, so the plant leaves and stems added more fuel for wildfires.

Physiological basis for variation in the competing ability of crops and weeds is their C_3 and C_4 photosynthetic pathways. Increase in CO_2 alone favors C_3 crops and weeds, but any simultaneous increase in temperature will benefit C_4 crops and weeds (Rajkumara 2007).

3. Distribution

Climate is the principal determinant of vegetation distribution at regional to global scales. It is expected that climate change will bring about a shift in the floral composition of several ecosystems at higher latitudes and altitudes, as changes in temperature and humidity will be reflected on flowering, fruiting and dormancy regimes. Weeds are able to spread into new territory. Climate change favors weeds that have already got established in currently restricted regions, enabling them to increase their range. As climatic zones shift, weeds that are capable of rapid dispersal and establishment have the potential to invade new areas and increase their range.

Weeds that are well-suited to adapt to the impacts of climate change may not only fill gaps left by more vulnerable native plants, but may have an even greater effect by altering the composition of ecosystems and their integrity. Weeds are typically of concern in areas where they are strong competitors rather than simply persisting at low densities without causing significant crop yield losses.

Patterson (1995) surmised that many weeds which are currently serious problems in the southern U.S. but do not occur at problem levels in the U.S. corn belt including the itchgrass (*Rottboellia cochinchinensis*), a profusely tillering C_4 grass, could invade the Central Midwest and California with only a 3° C warming trend. Witch weed (*Striga* sp.), a root parasite of corn, is limited at this time to the coastal plain of North and South Carolina. With an increase of temperature of 3°C, Patterson (1995) speculated that this parasite could become established in the Corn Belt with disastrous consequences. The current distribution of Japanese honeysuckle (*Lonicera japonica*) and kudzu (*Pueraria lobata*) is limited by low winter temperatures. Global warming could extend their northern limits by several hundred miles (Patterson 1995).

Other field observations indicated that potential weed migrations have been taking place due to elevated CO_2 levels. Kudzu was planted by state and federal agencies to control soil erosion throughout the Southern states in USA in the 1930s and '40s. Nowadays, it is creeping into northern states and is becoming an invasive weed (Ziska and George 2004). Johnsongrass (*Sorghum halepense*) will likely expand its historical range of damage to US maize with projected changes to climate. At present, *S. halepense* is not judged troublesome in the Northern Corn Belt, Northeastern States, or Great Lakes States. In coming decades, the damage niche will likely extend through much of the Corn Belt and into southern portions of the Northeastern States (Bridges 1992).

Many factors other than climate substantially influence actual species distributions including competitive exclusion, dispersal limitations, and patterns of disturbance. Annual cropping systems have several attributes that may make climate considerations particularly important for predicting future weed distributions. Weed dispersal processes are facilitated by the high level of habitat continuity in major cropping systems like maize production in the US and also by processes like tillage, manure spreading, and seed exchange that facilitate seed movement within and between farms (Cousens and Mortimer 1995).

However, cropping systems are likely to experience significant geographic range transformations among damaging endemic weed species and new vulnerabilities to exotic weed invasions. To anticipate these changes and to devise management strategies for proactively addressing them, it is necessary to characterize the environmental conditions that make specific weed species abundant, competitive, and therefore damaging to the production of particular crops (McDonald et al. 2009).

4. Management

Clearly, any direct or indirect impacts from a changing climate will have a significant effect on chemical management of weeds. Changes in temperature, wind speed, soil moisture and atmospheric humidity can influence the effectiveness of application of hebicides. For example, drought can result in thicker cuticle development or increased leaf pubescence, with subsequent reductions in herbicide entry into the leaf. Post-emergence herbicides can be dramatically affected by drought. Efficacy of post-emergence herbicides, particularly those that are translocated within the target weed, is highly dependent upon active weed growth. Thus, post-emergence herbicide applications should be made during periods of favorable conditions. Many post-emergence treatments are effective only on small weeds. In the presence of slight stress, higher rates of application may be necessary (if possible), or certain adjuvants may have to be added to enhance the efficacy of control. Some post-emergence herbicides have a temporary negative effect on crop growth. Under prolonged drought or heat stress, herbicide injury may reduce crop yields.

Preemergence herbicides are highly dependent upon rainfall or overhead irrigation for "activation" or movement into the zone of weed seed germination. Sunlight degrades some preemergence herbicides on the soil surface, and if rainfall or irrigation does not follow within seven to 10 days after application, poor weed control often results. Even for highly persistent herbicides, failure to move the compound into the soil due to the lack of rainfall allows weeds to germinate just after planting. With subsequent rainfall, these persistent compounds usually provide residual weed control of later-germinating weeds.

Drought may also influence herbicide carryover. Soil microorganisms play a significant role in degradation of many pesticides. Activity of soil microbes is favored by warm, moist conditions. Under dry conditions, microbial degradation slows and herbicide persistence in the soil is extended. For long-residual products which have specific restrictions relating to carryover, persistence is greater for incorporated rather than surface applications (Brown 2008).

The same variables can also interfere with crop growth and recovery following herbicide application. Overall, herbicides are most effective when applied to plants that are rapidly growing and metabolizing, i.e. those free from environmental stress.

Efficacy of chemical weed control may also be altered by climate change. If conditions become more humid and warmer, herbicide persistence will be shortened (Baily 2004). Canada thistle (*Cirsium arvense*) and quack grass (*Elytrigia repens*) become more resistant to herbicides when grown in higher concentrations of CO_2; making them harder to control. It was hypothesized that this may be a result of faster growth as the weeds mature more rapidly, leaving behind more quickly the seedling stage during which they are most vulnerable (Ziska et al. 1999; Ziska and Teasdale 2000).

Perennial weeds may become more difficult to control, if increased photosynthesis stimulates greater production of rhizomes and other storage organs. Changes in leaf surface characteristics and excess starch accumulation in the leaves of C_3 weeds may interfere with herbicidal control (Patterson 1995).

Potential changes in the weed biogeography of agricultural systems pose a challenge to management, but also an opportunity. If weed species can be identified as favored due to emergent climate conditions in a given region, nascent populations can be targeted for control before they become well established.

Besides changes in climate, agronomic practices for particular crops are not static in time and space; new classes of herbicides, cultivars, tillage innovations, irrigation techniques, and seed cleaning practices can all influence the geographic distribution and crop damage caused by weeds. For example, evidence suggests that the introduction of glyphosate resistant crops can significantly change weed community composition. Ecosystems with high levels of disturbance are more vulnerable to colonization by newly introduced plant species and are likely to reach a comparatively rapid equilibrium with emergent climate factors (Hobbs and Huenneke 1992; Milchunas and Lauenroth 1995).

If climate change brings about a longer growing season in temperate regions, spring weed emergence and growth may start earlier requiring an earlier control action. Early cultivations may be difficult with a shorter period of suitable conditions once fields become wet.

Biological control of pests by natural or manipulated means is likely to be affected by increasing atmospheric CO_2 and climatic change, both of which can alter the efficacy of weed bio-control agents by potentially altering the development, morphology and reproduction of the target pest. Direct effects of CO_2 would also be related to changes in the ratio of C:N and alterations in the overwintering stages, feeding habits and growth rate of herbivores (Patterson 1995). Although this could increase both the biological control of some weeds, it could also increase the incidence of specific crop pests, with subsequent indirect effects on crop-weed competition. Overall, synchrony between development and reproduction of biocontrol agents and their selected targets is unlikely to be maintained in periods of rapid climatic change or climatic extremes.

Overall, there are strong empirical reasons for expecting climate change and/or rising CO_2 to alter weed management. Adaptation strategies are available, but the cost of implementing such strategies (e.g. new herbicides, higher chemical concentrations, new biocontrol agents) is unclear. If an increase in CO_2 and temperatures allow invasive weed species to expand their geographical locations new herbicides may be needed to combat them.

Notwithstanding all these climate change impacts, weeds can be useful. For instance, Kudzu roots contain as much as 50 % starch by weight, and seem ideal for ethanol production, while the plant's supercharged vines, which can grow about 30 cm each day, would be an abundant source of alternative energy. This would be an alternative to fossil fuels and, at the same time, create a financial incentive to root out a particularly troublesome weed. Potential biofuel candidates are kudzu, swtichgrass (*Panicum virgatum*); jatropha (*Jatropha curcas*); giant reed (*Arundo donax*); chinese tallow tree (*Triadica sebifera*) and many others. Such plants are invasive in nature, and if introduced, should be under close management and must be treated cautiously (Low and Booth 2007).

Paradoxically, weeds had helped in dealing with lesser crises in the past. Weeds could hold the key to offering a solution, due to their characteristic genetic diversity. Plant breeders in the past have turned to combining the genetic resistance of wild, weedy plants with their domesticated relatives in order to decrease crops' vulnerability to disease and pests. Because weeds have more diverse genomes, it is easier to find one with the proper genetic resistance to a given threat — and then to create a new hybrid by breeding it with existing crops. An answer to the Irish potato blight of 1845-6 was eventually found among the potato's wild and weedy relatives; a wild oat in the 1960s was a source of genetic material that enabled breeders to develop a more robust, disease-resistant strain of domesticated oats.

Weedy ancestors of food crops could cope far better with coming climatic changes than their domesticated descendants. Weeds, our old adversaries, could be not only tools but mentors. Weeds by definition will cease to exist.

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Is climate change driving indigenous livestock to extinction? A simulation study of Jordan's indigenous cattle

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Abstract

Nearly all developing countries are promoting livestock production to meet the high demand of increasing population. Jordan is not yet self-sufficient in livestock products. Therefore, there is a need to increase productivity and numbers of livestock. However, the numbers of indigenous livestock is showing constant annual reduction. It is attributed to catastrophic events like drought and feed scarcity due to climate change (e.g. reduction in rainfall and increase in temperature). This is currently a major force driving livestock into extinction. The objectives of this study were to simulate the extinction probabilities (*PE*) of the indigenous cattle of Jordan under the effect of different drought levels using Vortex® modelling program. Using the census data, effective population size (N_e) was calculated and found to be almost half (N_e = 40) of what is recommended (N_e = 82) by FAO to escape endangerment. Furthermore, the PE, growth rate, heterozygosity and inbreeding rates were simulated for a 25 year past and future time horizon. The model indicates that the number of indigenous cattle is currently expected to decline rapidly toward extinction within the coming years assuming that the conditions of less rain, more drought and feed scarcity would continue.

Keywords: climate change, extinction probability, indigenous cattle breed, modelling.

1. Introduction

Several systems for assessing the endangerment of livestock breeds have been proposed (see for example FAO 1995; European Commission 1992; DGfZ 1991). The three evaluation systems mentioned above use a threshold number of breeding female of less than 5000, breeding male less than 20, and breeding herds less than 10 for the assessment as to whether the breed is endangered. However, instead of any arbitrary number of breeding animals per breed taken from census records, the DGfZ (1991) has proposed the effective population size (*Ne*) as the main factor for such assessment.

The *Ne*, according to population genetics theory (Falconer 1989), is an indicator of random genetic drift and of the decrease in variation within breed as a group of interbreeding animals. On the other hand, conservation process is only possible for endangered breed when a diversity conservation plan is well established. It was recommended that the conservation plan should be on the basis of comprehensive identification of endangered breeds considering population viability analysis (PVA) (Simianer et al. 2003). PVA, as originally described, is a method of quantitative analysis of a population to determine the probability of extinction (PE). More broadly, PVA is the estimation of PE and other measures of population diversity by the analyses that incorporate environmental conditions, threats to persistence, and future management actions over defined time periods (Brussard 1985; Gilpin and Soule 1986; Burgman et al. 1996; Lacy 1993/1994).

A number of conservation biologists have focused on methods for estimating PE over defined time periods from a small number of measurable parameters. One of the successful attempts is the use of Vortex®, a computer program that estimates PE through a simulation of effects of deterministic forces as well as stochastic events on small animal populations (Lacy 2000). Although suitable computer programs for measuring diversity are available for livestock breeds, only a little has been known so far about the extinction probabilities of indigenous livestock breeds (Reist-Marti et al. 2003; Bennewitz and Meuwisse, 2005; Bennewitz et al. 2006). In contrast to livestock breeds, the estimation of extinction properties for endangered wildlife species is frequently conducted in various manners and for various purposes (Lindenmayer et al. 1995; Brook et al., 2000).

Because of increasing frequency of events of drought and feed scarcity, probably due to climate changes (e.g. decreasing rainfall and increasing temperatures), indigenous cattle have shown fast drops in census number in the last 25 years in Jordan (Jordan Ministry of Agriculture 2006). For example, in the year 1982, the total number of cattle was 22,141 while in the year 2006 it was only 1,880. So, without any conservation efforts, the Jordanian indigenous cattle might face extinction in foreseeable future. The objectives of this study were to find out whether indigenous Jordan cattle breed is becoming endangered to extinction, to simulate the extinction probabilities of the breed under the current living conditions, and to provide information needed for the conservation program to prevent extinction.

2. Materials and methods

2.1. Breed appearance and adaptability

A brief description of the indigenous cattle appearance and performance is offered due to the lack of current literature about the breed. The indigenous cattle of Jordan (locally called Baladi) are a beef breed with high work ability (Mason 1996). It is hardy and well adapted to local environments of dry areas of western part of Jordan and is resistant to tropical diseases (Harb and Khald 1984). The breed is reared and restricted to areas in different governorates that are outside of the Jordan Rift Valley. The hardiness of the breed is believed to have resulted from natural selection under the local environment and the management practices of their owners. The animals are relatively small, short legged, with medium neck length, upstanding, and with well formed body. The color varies from brown to black. Horn condition is variable: polled and horned. Milk yield averages 3,864 liter per lactation period of 335 days under station condition. Their first calving occurs on an average at the age of 36 months; dry period is 225 days, and calving interval is 515 days. The body weight at maturity for male and female is 328 and 270 kg respectively (Harb and Khald 1984; FAOSTAT 2001).

2.2. Census data

The number of recorded indigenous cattle was available for twenty five years, but with missing information for some years (such as 1983, 1985 and 1997), from the Jordan Ministry of Agriculture (1984, 2006). Hence data for even years within the 25-year period were taken for cows, bulls, heifers and bullocks of the indigenous breed (Table 1) for estimating effective population size, inbreeding rate and EP analyses.

Table 1. The number of indigenous cows, bulls, heifers and bullocks in registered records of indigenous Jordan cattle breed from 1982 to 2006.

Year	Cows	Bulls	Heifers	Bullocks	Total number (N)
1982	13755	1771	3905	2710	22141
1984	12225	1186	4305	1805	19521
1986	9328	160	4354	1700	15542
1988	6365	234	3281	2002	11882
1990	6485	276	3661	942	11364
1992	6043	321	3472	691	10527
1994	5296	277	3197	1210	9975
1996	4571	179	2472	1237	8459
1998	4558	161	2332	1192	8243
2000	2434	99	1021	703	4257
2002	2044	46	831	366	3287
2004	1529	21	538	222	2310
2006	1417	10	235	218	1880

2.3. Estimation of effective population size and inbreeding coefficients

Estimate of effective population (*Ne*) has been used instead of normal population size (*N*) to determine whether the breed was endangered or not (Falconer 1989). *Ne* is an important parameter determining the genetic structure of small populations. The *Ne* was estimated on the basis of the number of breeding livestock animals as described by Ollivier and James (2004). For a typical livestock population where the number of breeding males (Nm) is different from the number of breeding females (Nf), as is the case in the present study, the *Ne* was estimated as $Ne=4(Nm \times Nf)/(Nm+Nf)$ (Falconer 1989). The rate of inbreeding (F) was estimated according to the formula $F=1/(2Ne)$ (Falconer 1989).

2.4.The PVA model

Estimation of extinction probability

Extinction probabilities were estimated using population viability analysis model of Vortex®, which used a Monte Carlo simulation of the effects of defined deterministic forces as well as demographic, environmental, and genetic stochastic events on the indigenous cattle population. The program began by creating individuals to form the starting population and then stepped through life cycle events on an annual basis (for a more detailed explanation of Vortex® and its use in population viability analysis, see Lacy 2000). Stochastic events such as breeding success, progeny number, sex at birth and mortality rate were determined by already defined probability density function. Consequently, each run (iteration) of the model gave a different result and by running the model hundreds of times, a range of possibilities and outcomes were examined. Vortex® was provided with all events and biological parameters that were necessary to run PVA model for the examination of the fate of the indigenous cattle population through each year of its lifetime in the population dynamics. For the purposes of each simulation, the extinction was defined as any case where the population number was less than or equal to 1 ($N \leq 1$) and/or one sex was extinct. The PE was determined by dividing the number of iterations that went extinct by 1000. This produced a percentage of iterations that reached extinction during the simulation.

The model description and assumptions

The modeling exercise required a set of parameters to describe the biological characteristics and stochastic events of the cattle population. Vortex® simulated the populations by stepping through a series of events that describe an annual cycle of a typical sexually reproducing, diploid organism, mate selection, reproduction, mortality, increment of age by one year, removals, supplementations, and then truncation to the carrying capacity (Table 2). The parameters were derived using a combination of published and unpublished data (Harb and Khald 1984; FAOSTAT 2001). Unpublished data were collected from farmers and animals on their farms. The data and parameters are summarized in Table 2.

While many of the data are straightforward, some deserve further discussion. For example, inbreeding depression is incorporated using the lethal recessive alleles model. Vortex® mammalian default settings of 3.14 for lethal equivalents and 50% due to recessive lethal were used. This is due to the unavailability of such data for indigenous cattle breeds. Age of first offspring was entered as 3 and 2.5 years for males and females, respectively. The annual maximum number of progeny per female was listed as 2, in case of twins. The maximum age of reproduction was entered as 10 years. An equal sex ratio value was assigned for males and females at birth. The percentage of adult females breeding was listed as 90. The percentage of males in the breeding pool was listed as 90. No harvest and supplementation population data were used in the analysis. Amount of annual variation in each demographic rate caused by fluctuations in the environment was specified (Table 2).

Concordance between environmental variation in reproduction and survival was considered. It was believed that there is a positive correlation between environmental conditions that affect survival and reproduction for indigenous cattle (i.e. years that are good for survival tend to be good also for reproduction and vice versa). Feed scarcity and drought were included as catastrophic eventss in the model. Each was modeled as a separate type of catastrophic event to simulate the reduction in population size. The frequency of each type of studied catastrophic events (drought=25% and feed scarcity=25%) and the effects of the catastrophe on survival and reproduction were specified for both as 25% and 75%, respectively.

Table 2. The demographic input parameters for basic Vortex® model used for simulation of indigenous cattle populations.

Input parameter	**Value**
Breeding System	Long-term polygynous
Age of first reproduction (female/ male) (year)	2.5/ 3
Inbreeding depression?	Yes
Lethal equivalents	3.14
Recessive lethal %	50
Density dependent reproduction?	No
Maximum parity size (calf)	2
Mean parity size (calf)	1.1
Overall offspring sex ratio	1:1 (50% male, 50% fermale)
Initial population size (Animal)	22141
Maximum breeding age (senescence) (year)	10
Sex ratio at birth (percent males) (%)	50
Adult breeding females (%)	90
Females produce 1 progeny in a year (%)	100
Mortality of females between ages 0 and 1 (%)	5
Mortality of females between ages 1 and 2 (%)	2
Mortality of adult females (2≤ age≤ 10) (%)	1
Mortality of males between ages 0 and 1 (%)	5
Mortality of males between ages 1 and 2 (%)	2
Mortality of adult males (2≤ age≤ 10) (%)	1
Catastrophe type 1: Feed scarcity	
Frequency (%)	25
Multiplicative effect on reproduction (%)	75
Multiplicative effect on survival (%)	25
Catastrophe type 2: Drought	
Frequency (%)	25
Multiplicative effect on reproduction (%)	75
Multiplicative effect on survival (%)	25
Mate Monopolization	
Females are in the breeding pool (%)	70
Males are in the breeding pool (%)	30
Males successfully siring offspring (%)	27.1
Number of mates/successful sire	2.6
Harvested Populations	No
Supplemented Population	No

Mortality figures that were used in the analysis are detailed in Table 2. The analyses were run for each starting population using different mortality rates for different classes of age. Deterministic projections assumed no stochastic fluctuations, no inbreeding depression, no limitation of mates, no harvest, and no supplementation. In addition, mating was modeled as long-term polygynous. Initial size of real population (22,141 animals) was set at carrying capacity. The Vortex® distributed the specified initial population among age-sex classes according to a stable age distribution that is characteristic of the mortality and reproductive schedule described initially for the model.

Simulation scenarios

The Vortex® was used to compile the past population dynamics and future risk of population decline or extinction under the current management scenarios. Thus the modeling section was divided into two simulation scenarios. In the first scenario, the aim was to mimic the past dynamics of the population within studied time frame (25 years).

The assumptions and outcomes of this part such as estimated marginal diversities, reduction in growth rate and harvest were implemented in the second scenario, which simulated the parameters of past population dynamics for the future time horizon of another 25 years to predict future PE. In both scenarios, the simulation of the population was iterated 1000 times to generate the distribution of fates that the population might experience. The outcomes and outputs of simulations that mimic reality were used to simulate the variability that the population might experience in the future.

3. Results and discussion

3.1. Normal and effective population sizes and inbreeding rate

The census data (Table 1) showed a reduction in the number of recorded indigenous cows. The indigenous breed belongs to the Middle East area which is described earlier as beef type dual-purpose breed (Mason 1996). However, until the time of introducing exotic cattle breeds in the country it was used by farmers purely for milk production. With the introduction of exotic breeds, which were recorded as foreign milch cows in the register, the indigenous milch cows were also recorded in that group (Jordan Ministry of Agriculture 2006). As a consequence, the number of recorded indigenous cows in the past two decades steadily decreased (Table 1). In 1982, the total population size of indigenous cattle was 22,141, whereas it became 1880 in 2006. This current size of indigenous breed is very small and close to final extinction size of livestock breeds. In particular, very few mature bulls (only 10) are still alive.
According to FAO World Watch List (1995) a breed of cattle is not considered endangered when the total number of breeding females and males is more than 1000 and 20, respectively. On the other hand, Fries and Ruvinsky (1999) suggested that if the minimum number was between 10,000 and 750 the breed should not be considered as endangered. Since the current number of indigenous cattle in our study (1880) is falling within these ranges, it would be assumed that this breed is not endangered. However, the number of breeding males of the indigenous cattle is 10 which is less than the threshold recommended by FAO (1995). Therefore, one could argue that the Jordan indigenous cattle breed is endangered and needs to be conserved.

To resolve the above issue, it would be better to predict the need for conservation on the basis of *Ne* rather than *N*. The *Ne* values and the inbreeding coefficient (*F*) estimates are presented in Table 3. The current *Ne* for this breed was 40, whereas two years earlier it was 83. The FAO (1995), EAAP (2005) and European Commission (1992) set Ne of less than 82, 84, and 400, respectively, as a critical and endangered level. Therefore, the indigenous Jordan cattle breed was not endan-

Table 3. The normal (*N*) and effective (*Ne*) population sizes and calculated and simulated inbreeding rate (*F*) of indigenous cattle breed from 1982 to 2006.

Year	*N*	N_e	Calculated *F*	Simulate *F*
1982	22141	6276	0.0001	0.0000
1984	19521	4324	0.0001	0.0000
1986	15542	629	0.0008	0.0000
1988	11882	903	0.0006	0.0000
1990	11364	1059	0.0005	0.0001
1992	10527	1219	0.0004	0.0001
1994	9975	1053	0.0005	0.0001
1996	8459	689	0.0007	0.0001
1998	8243	622	0.0008	0.0002
2000	4257	381	0.0013	0.0002
2002	3287	180	0.0028	0.0002
2004	2310	83	0.0060	0.0003
2006	1880	40	0.0125	0.0003

gered in 2004, but was indeed facing extinction in 2006. In such a case, *ex-situ* and *in-situ* conservation programs would have to be used to conserve this breed.

The rate of inbreeding has increased (Table 3) probably due to the small number of animals in the breeding pool. The increasing trend in the rate of inbreeding corresponds to the trend of decrease in *Ne*. This is in agreement with population genetics theory as *Ne* is an indicator of the increase of the coefficient of inbreeding per generation (Falconer 1989).

3.2. PVA simulation results

This section is divided into two parts. In the first part, the simulation results of the study that mimic the past time horizon of reduction in population size till current time of this study, 2006, are presented and discussed. The second part describes the assumptions of the applied PVA model and their validity to expect the extinction time horizon of the population.

Simulated population dynamic for past time horizon

The results of this analysis are presented in Figure 1. The past simulated population dynamics started with a population size of 22,141 which fell to 1881 after 25 years. The simulated population did not become extinct and reached a mean rate of stochastic population growth (r) of 0.303. This growth rate was calculated for each year of the simulation, prior to any truncation of the population size due to the population exceeding the carrying capacity (Fig. 1). The PE values after 25 years are zero, determined by the proportion of 1000 iterations for the given population. The mean population size (*N*) at the end of the simulation was averaged across simulated population (Fig. 1). The gene diversity or expected heterozygosity (He) of the population, expressed as a percent of the initial gene diversity, is 100%.

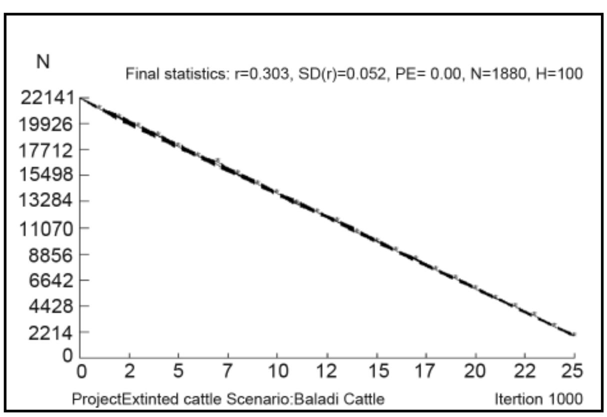

Figure 1. Plot of the individual iterations of the baseline Vortex® model of cattle population dynamics in the past 25 years. Final statistics (N: population size, r: Growth rate, PE: probability of extinctions, H: heterozygosity).

Fitness of individuals usually declines proportionately with gene diversity decrease as a result of inbreeding. In practice, the rate of inbreeding (Table 3) would not influence the population dynamics as long as the breed size remained above the defined value of *Ne*. The similar findings have reported by Meuwissen (1997) and Sonesson and Meuwissen (2001). Therefore, the individuals in the population were of reasonable fitness to prevent the population from extinction at the end of the simulation time frame. It is clear however that the population is currently expected to decline rapidly toward extinction within the next few coming years. The high rate of decline seen in the model is, at least in part, due to pessimistic estimates of certain key demographic parameters, such as the percentage of adult breeding males or the age of first reproduction. However, this decline also resulted from the catastrophic events expected. Due to continuous decrease in the past population size, the breed had annual reduction rate and deterministic population growth rate of−3.75 and 1.472, respectively over the 25 years. The negative growth rate has been reported to be the main reason of the decline in population size and losing diversity (Bennewitz and Meuwissen 2005). Therefore, the population growth was reducing over years even if the stochastic growth rate was positive (0.303). Similar results were found by Gandini et al. (2004) across alternative scenarios in which the expected loss of diversity was estimated only as a strong decline in population size.

When the simulated population dynamics was compared with actual population dynamics (Fig. 2), there was some variation. At the beginning of the simulation, simulated population dynamics mimicked natural values. The real population size however dropped down far from simulated population size in some years. These were the years in which unexpected catastrophic events occurred, which is expected for any real population under farm conditions or wildlife in their own habitat. In early 1980s, the exotic dairy cows of high productivity were heavily introduced in Jordan (Jordan Ministry of Agriculture 2006). This led to replacing the indigenous cows in many farms and a sharp reduction in their number. The effect was obvious from 1986 to 1990. Thereafter, the population size steadily increased in the early 1990s and the real population size came close to the simulated size in the period 1992–1998. By the beginning of the new millennium, the real size suffered again sharp reduction as a result of drought and feed scarcity that occurred in 1999–2001.

Shaffer (1993) divided the factors that affect the population dynamics into the following random variables: environmental fluctuations, demographic fluctuations, genetic uncertainty, and catastrophic events. In particular, catastrophic events occur with a low probability but drastically reduce the population size within a short period. The model in this study considered only two variables as important as catastrophic events, the feed scarcity and drought, because their effects were permanent and unpredictable. Additional factors that might affect the population dynamics (e.g. diseases, predators, production system, etc) were not considered as these factors were of less importance for this population.

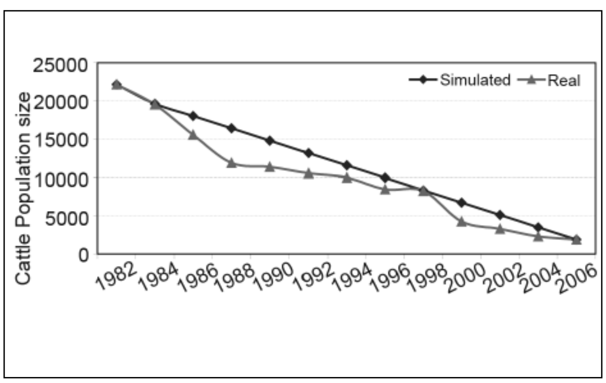

Figure 2. Real and simulated indigenous cattle population dynamics in past 25 years (from 1982 to 2006).

It is important to mention that the time span of 25 years might be too short for getting accurate knowledge about any population dynamics (Fig. 3). The time span is short because in 25 years there are only 10 generations. On the other hand, the reliability of population growth rate estimates is better for a short time span (Goodman 1993). Therefore, it would be better to estimate an expected future diversity for every two years up to

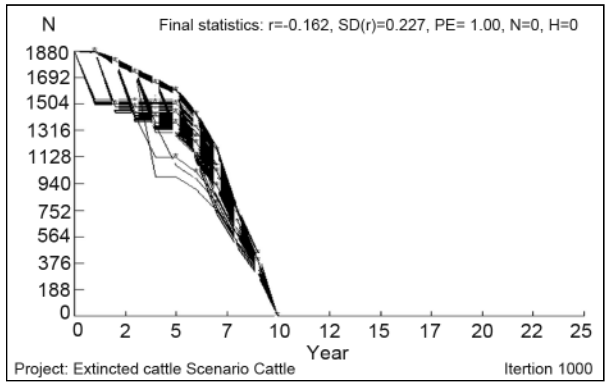

Figure 3. Plot of individual iterations of the simulation model of indigenous cattle population dynamics in future 25 years using Vortex®. Final statistics (N: population size, r: Growth rate, PE: probability of extinctions, H: heterozygosity).

the end of the time horizon of 25 years than to do so for a longer time. This would provide a clear impression of the pattern of change of the expected loss of diversity with increasing time beyond the studied period. A good agreement between the simulated and the actual population size indicates that the model is a fairly accurate simulation of the likely fate of this population in the current living conditions.

Extinction probabilities for future time horizon

Fig. 3 presents an expected diversity for every two years for 25 years in the future, as well as provides a pattern of change in diversity. The figure shows the average population growth rate, the EPs over future 25 years, and heterozygosity to be, respectively, −0.162, 100% and 0. It is clear that the population is expected to decline rapidly toward extinction within the next 10 years. Note that the population crashed at the beginning of the simulation, simulating the effects of drought and exotic breed competition. In most instances the cattle population was able to grow following the crashes as the population size (carrying capacity) recovered, but the population is particularly susceptible to extinction when it is low in numbers. The population extinction occurred around iteration time step of 651 in this analysis.

The high rate of decline seen in the model was due, at least in part, to low number of adult females and the mating of the females with exotic males in an attempt to produce new more productive offsprings. However, feed scarcity might have also contributed. Our future uncertainty about the magnitude of environmental events and the severity of catastrophic events emphasizes the importance of continued monitoring of the indigenous cattle population to ensure its long-term persistence. As additional information becomes available the PVA model can be revised and if necessary corrective management measures can be implemented.

The most informative results of the applied PVA model are the plots of EP against a series of defined future time horizons (Fig. 4). The EP increases in a relatively linear fashion over time. The EP of any population has to be taken into account in order to draw inference from the present diversity about the expected future diversity (Weitzman 1993; Simianer et al. 2003). Additionally, this strategy allows the estimation of the marginal diversity of a breed, which is defined as the change of the diversity at the end of a defined time horizon when the extinction probability of the breed would be changed by one unit, as it is shown in Fig. 4.

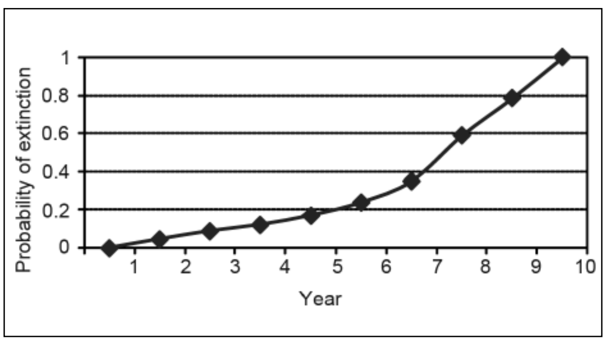

Figure 4. Cumulative extinction probabilities plotted against the future time till the extinction.

4. Conclusion

The indigenous Jordan cattle population is indeed facing extinction as its *Ne* is almost half of the recommended level to escape danger of extinction. It is recommended that the *ex-situ* and *in-situ* conservation programs should be undertaken to conserve this breed. The study also shows that PVA model is good in predicting the future dynamics of the populations based on past time as it mimicked well the past time dynamics. The model successfully reflected the effect of feed scarcity and drought that occurred probably because of the climate change (less rainfall and high temperature). Although there was some variation between the simulated and the actual population size, the model was a fairly accurate simulation of what was happening with population during the past living conditions. The model predicts that the population is currently expected to decline rapidly toward extinction within the coming 10 years in the absence of a conserving genetic management program.

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Theme 4: Mitigation, Adaptation and Ecosystem Resilience Strategies Including Natural Resource Management and Crop Improvement

Plant genetic resources management and discovering genes for designing crops resilient to changing climate

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Abstract

Climate change is expected to result in increased frequency of drought, heat stress, submergence of land, increased soil salinity, etc. Much of the existing literature assumes that farmers will automatically adapt to climate change and thereby lessen many of its potential negative impacts, taking for granted the monumental past efforts at the collection, conservation and utilization of plant genetic resources on which much of the farmer's adaptation has historically depended. Given potentially large climatic changes, it is dangerous to assume that adaptation of cultivars will happen automatically. Extensive crop breeding that relies on access to genetic resources will almost certainly be required for adapting crops to climate change. Key to successful crop improvement is a continued supply of genetic diversity including new or improved variability for target traits such as early flowering as a mechanism to escape drought, root characteristics, water use efficiency, amount of water transpired, transpiration efficiency, osmotic adjustment, stem water soluble carbohydrates, stay green and leaf abscisic acid content. The core/minicore collections developed in many genebanks can provide new sources of variation for beneficial adaptive traits to climate change. Substantial knowledge and insight is therefore needed to gauge what type of diversity now exists in the genebanks, and what will be needed in the future. Greater investments need to be made in phenotyping and genotyping the native genetic variation contained in seed banks and collecting the remaining diversity, particularly that associated with traits of value to crop adaptation to climate change. Plant breeders and other users of genebank collections should play a key role in shaping these efforts to ensure that the end result is useful.

Keywords: climate change adaptation, gene prospecting, plant genetic resources.

1. Introduction

There is broad consensus among some 20 global climate models considered by the Intergoverment-Panel on Climate Change (IPCC) that climatic conditions are changing significantly at regional and global scales, and that the climate at the end of this century will be substantially warmer than that of the past century (Naylor et al. 2007). There is widespread agreement on three points in particular: a) all regions will become warmer, b) soil moisture will decline with higher temperatures and evapotranspiration in the sub-tropics, leading to sustained drought conditions in some areas and flooding in other areas where rainfall intensity would increase but soil moisture would decrease, and c) sea level will rise globally with thermal expansion of the oceans and glacial melt.

In order to promote agricultural adaptation in the face of such dramatic changes in climate, substantial crop breeding efforts will be required to develop adapted cultivars, which will depend on the collection, conservation and distribution of appropriate crop genetic material among plant breeders and other researchers. Assessing the potential impact of climate change on crop productivity in years to come and identifying priorities for immediate collection and breeding is therefore an important first step in ensuring longer run adaptation.

2. Changes in climate extremes and crop responses

For an empirical model a total of 94 crop-region combinations were evaluated by IPCC, ranging from the most important global crop (rice in South Asia) to globally less important crops (groundnuts in East Africa). The results show that South Asia and Southern Africa are two "hunger hotspots" that are likely to face the most serious impacts of climate change. The crop facing the single largest potential impact is maize in Southern Africa where losses in production of up to 30% may occur by 2030.

In South Asia, where roughly one-third of the world's malnourished live, several key crops– wheat, rice, rapeseed, millet, and maize – have more than a 75% chance of incurring losses from climate change. The potential impact of climate change on agricultural productivity remains highly uncertain in other "hunger hotspots", such as West, Central, and East Africa, where the quality of data was inadequate for reliable evaluation.

Results from a set of crop models from India for rice and wheat were consistent with the general direction of decline in production and have raised serious concerns for the future state of hunger in South Asia (IFPRI 2009). According to ADB (2009), the Asian countries most vulnerable to climate change are Afghanistan, Bangladesh, Cambodia, India, Laos PDR, Myanmar and Nepal. Afghanistan, Bangladesh, India and Nepal are particularly vulnerable to declining crop yields due to glacial melting, floods, droughts, and erratic rainfall, among other factors. Asia is the most disaster-afflicted region in the world, accounting for about 89 percent of people affected by disasters worldwide because more than 60 percent of the economically active population and their dependents – 2.2 billion people – rely on agriculture for their livelihoods in this region.

All the regions are going to face higher temperatures in the next few decades, consistently breaking records both for average growing season temperatures and number of days above critical thresholds, such as 35 °C (Lobell 2009). Moisture levels will decrease in several important growing areas, including much of North America, Europe, Africa, Central America, and Australia. Although the understanding of the physiological response of crops to high temperatures is rather limited (Lobell 2009), there is strong evidence that yields of maize (and several other crops) exhibit a nonlinear reduction when exposed to temperatures exceeding 30° C. Faster crop development and soil drying with higher temperatures are likely the two key processes determining overall temperature response to climate change. Other effects of high temperatures, including those on photosynthesis, respiration, and heat damage of reproductive organs are less understood.

Estimates of climate change impacts are often characterized by large uncertainties, which reflect lack of adequate understanding of many physical, biological, and socio-economic processes. This hampers efforts to anticipate and adapt to climate change. A key to reducing these uncertainties is improved understanding of the relative contributions of individual factors. Uncertainties for projections of climate change impacts on crop production were evaluated for 94 crop–region combinations that account for the bulk of calories consumed by malnourished populations (Lobell and Burke 2009). Specifically, the focus was on the relative contributions of four factors, climate model projections of future temperature and precipitation and the sensitivities of crops to temperature and precipitation changes. Surprisingly, uncertainties related to temperature represented a greater contribution to climate change impact uncertainty than those related to precipitation for most crops and regions, and in particular the sensitivity of crop yields to temperature was a critical source of uncertainty. It was concluded that progress in understanding crop responses to temperature and the magnitude of regional temperature changes are two of the most important needs for climate change impact assessments and adaptation efforts for agriculture.

3. Crop collection and evaluation

There is urgency for genetic conservation and breeding investments to enhance crop adaptation to future climates. But the major question remains: are the available crop genetic resources and the associated information adequate for such breeding efforts? There are about 150 different crops traded in the world market, only 35 of which are covered within the ITPGRFA - a treaty that sets a multilateral legal framework for facilitated exchange of genetic resources across borders. There are also thousands of crops/species that are consumed and traded locally but do not enter the world trading system; much of the genetic diversity for these crops is not stored in gene banks. Finally, there are over one billion people living in families that are self-provisioning in the seeds they plant each year, and who serve as the *in situ* conservers of abundant crop genetic diversity for both traded and non-traded crops. The need for *ex situ* storage of diverse crop genetic material is thus becoming increasingly urgent in the face of rapid changes in land use and climate worldwide, and potential displacements of landraces by improved crop varieties.

There are roughly 1600 gene banks around the world that contain some 6 million accessions of crop genetic resources, 1.5 million of which are thought to be distinct or unique. The size of gene banks varies substantially; for example, the Chinese national gene bank holds about a half million accessions, while national banks in some other parts of the world hold only a few thousand, and institutional collections may consist of as few as one or two accessions. How much of the world's crop genetic material has actually been collected and is now being conserved *ex situ*? It is thought that 95% of the genetic diversity of the world's major cereal crops - rice, wheat, and maize - has been collected. For regionally important crops, such as cassava, which is one of the world's most important root crops, only 35% of genetic diversity is thought to have been collected. Many locally important crops have no significant genetic collections at all. Moreover, the characterization of existing genetic material remains a huge hurdle for many gene banks, especially for minor crops. The storage of the diversity of vegetatively propagated crops is especially difficult and expensive; as a consequence, collections tend to be small and vulnerable. The combination of relatively small number of accessions of minor crops and minimal numbers of breeders working on them is a major constraint in enhancing the adaptation to climate change in these crops.

Wild relatives should play a key role in crop genetic improvement under conditions of climate change, because they are generally more diverse and have adapted themselves to all sorts of evolutionary forces over time. They are thus expected to contain a wealth of adaptive traits. But unfortunately they remain a relatively low priority in collection due to financial and political impediments. The collection of wild relatives is a challenge in terms of expertise, access, and expense. Additionally, and for the moment, there is also some understandable resistance to their use by many breeders as the wild forms contain a large number of undesirable traits that must be eliminated in the final commercial cultivar. This constraint is likely to diminish as more refined biotechnological tools are integrated with breeding in future crop improvement efforts, permitting more precise insertion of genomic segments from the wild into improved germplasm.
The National Genebank at NBPGR, New Delhi, presently holds about 0.38 million accessions (375,371 accessions of over 1,500 crop species in 'Seed Genebank', over 2,000 accessions of 158 plant species in '*In vitro* Genebank' and more than 8,900 accessions of 726 plant species in the 'Cryo-bank'). The share of cereals (145,765 accessions) is the largest, with rice alone having 87,864 accessions.

4. Distribution of wild crop relatives *in situ*

The vulnerability of *in situ* wild relatives to climate change is an important issue. Studies on current and future species richness for wild crop relatives paint a grim picture (Naylor et al. 2007). For example, the study of the distribution of wild peanut species in South America, cowpea species in Africa, and wild potato species in Central and South America suggested that (a) most of these species are expected to lose over half of their range area by the middle of this century due to climate change; (b) all of them will likely move up in elevation, and some will shift in latitude; and (c) some 16-22% of them might get extinct.
There is therefore a need for more collection efforts in the short run before diversity is lost.

The diversity of wild relatives of key agricultural species in the world's "Centers of Origin" is being lost due to the changes in land use and other forces. Unfortunately, most accessions have not been fully geo-referenced, so mapping the origin of existing *ex situ* material in gene banks is imprecise or nonexistent. More work is needed to geo-reference existing collections, improve the quality of existing data, and make this information widely available to the international community in order to support ongoing efforts to model wild species distribution and change over time.

The other important genetic resource, the uncollected farmers' varieties (landraces) still found largely in the fields of small and subsistence farmers in the developing countries, faces challenges similar to those faced by the wild relatives. An estimated more than one billion rural households are thought to be provisioning their own seed supply. The loss of these varieties to climate change will not only deprive the future generations of an immense source of diversity, but will also result in extreme hardship to some of the poorest of the poor as they will steadily lose their farm productivity and resilience (Naylor et al. 2007).

5. Priorities and actions

The four priority actions - developing trait-based collection strategies, collecting material at the extreme ends of genetic diversity, establishing prebreeding as a public good, and educating key players about the importance of conserving genetic resources in the face of climate change - require immediate attention by all concerned.

5.1. The collection challenge

Several questions arise when one considers the collection strategy for adaptation to climate change. Which species to collect and conserve – ones that are expected to experience the greatest negative impact or the ones that would be least impacted in the future? Should one work for the existing cropping systems or to transition toward crops more likely to tolerate climate change in a particular region? That is, should we be focusing on obstacles or opportunities? Will national seed banks as currently configured become less important in the future as climatic ranges for crops change? Will material currently stored in national banks be more useful in other countries and less to their current holders in the future? Are national gene banks over-valued, and will international seed collections become increasingly valuable? Should efforts be placed on minor crops such as sorghum, millets, and yams (which have relatively small collections or collection centers and are grown in regional niches) instead of maize (which has large public and private collections and is grown globally) or vice versa? Should the major target be crops consumed by the largest number of people, or poor people, or by the people in the areas having largest concentrations of poor people? How are these numbers and rates expected to change in the future? Should the focus of collection be at the extremes of genetic diversity given the magnitude of climate change expected by the end of the century? Should the wild relatives be given priority? Should activities be geared toward the expected climate in 2030, 2050, or 2100?

These questions were raised in the discussions during the Bellagio Conference on 'Plant Genetic Resources in the Face of Climate Change' (Naylor et al. 2007). As an initial focus of collection, it was decided to consider crops such as rice, wheat, maize, sorghum, millets, groundnut, rapeseed, cowpea, pigeon pea, lentil and cassava. Certain other crops such as sweet potatoes, potato, bananas, and grass pea (*Lathyrus*) might also have a legitimate claim. This list represents crops most likely to be affected by climate change; crops most widely consumed by the poor; crops with high nutritional qualities for the poor; and "safety crops" that can tolerate climate fluctuations. Most, but not all, of these crops are listed within the International Treaty on Plant Genetic Resources. In addition, there was a general agreement on the traits of interest to be targeted: (a) Temperature (length of growing season, flowering, sterility, protein content); (b) Precipitation (drought and flood tolerance, as well as the timing and quantity of rainfall in general); and (c) Pest and pathogens, including those associated with post-harvest losses.

With these crops and traits in mind, it would be worthwhile to examine regions where the climate is already extreme and representative of expected future climates. The following two elements should be an integral part of any collection strategy to prepare for climate change adaptations:

- The collection should be more focused so that the appropriate traits are captured within the genetic material of a wide variety of crops to promote successful breeding for climate change. Gene sources for valuable traits can be used within and across species. The latter does not necessarily imply the indiscriminate use of GMOs; the concepts of homologous series and synteny can be used to identify useful traits within families for breeding purposes (Naylor et al. 2007).
- Given the expected magnitude of climate change by 2100, it was agreed that the international community needs to conserve a wider range of genetic diversity before it is lost forever. For this,

there is a need to have a better understanding of wild relatives and their distributions; landraces and their distributions; climate sensitivity of different species (wild and cultivated); and genetic material currently in the gene banks. The skills needed to accomplish these overlapping objectives include taxonomy (for identification of wild relatives), species distribution and performance modeling (for mapping wild relatives and landraces), genetic tools for evaluation, and climate impact analysis (Naylor et al. 2007).

5.2. The breeding challenge

With a focus on the collection of genetic material for traits and at the extreme ends of the diversity scale, a major constraint on linking collections to breeding in the future has been unveiled. Crop breeders are usually rewarded for developing the new and improved cultivars released and used widely by farmers and accepted by consumers over a given time period; the incremental gain reflected in them; and their eventual economic success. Breeders are not typically rewarded on the basis of a single cultivar developed over an unlimited breeding period unless the cultivar is exceptional and has lasting success. Based on this incentive structure, most breeders work with a generally limited segment of the core genetic collection available to them - the segment of genetic diversity that has sufficient variation and has performed well in the past. Breeders are generally reluctant to explore the genetic material in wild relatives, because the wild relatives contain too much random genetic information (having evolved in response to multiple forces in the wild) for efficient identification and isolation of traits. Yet the genetic material at the extreme ends of landrace diversity and within wild populations is likely to be essential for successful breeding in the face of global climate change. Moreover, this diversity, which is so important to future adaptation to climate change, may itself fall prey to climate change. As a result of the mismatch between breeders' incentives and the potential value of genetic material in wild relatives and the extreme ends of landrace diversity, strategic priority on the initiation of programs for pre-breeding has been placed.

Pre-breeding would entail the evaluation of genetic material at the extreme ends, using available and conventional tools that remain powerful (e.g., cytogenetics). Such an effort would require substantial time and resources. Given that an increasing share of crop genetic material used for breeding is being privatized, it is essential that genetic resources be maintained in the public domain, i.e., under the terms of the International Treaty, for pre-breeding efforts, and that the results be publicly available to the global community of breeders. Gene banks have an important role to play in pre-breeding, particularly given breeders' reluctance to explore crop wild relatives.

5.3. Development of core collections for promoting germplasm use

Core collection of plant genetic resources is a collection which contains, with a minimum of repetitiveness, maximum possible genetic diversity of a crop species and its wild relatives (Frankel 1984; Frankel and Brown 1984; Brown 1989a, b). The essential features of core collection are restricted size, structured sampling of species or collections, and diversity. It is not intended to replace existing genebank collections but to make the variation contained within such collections more accessible to users. Core collections have been initiated for a wide variety of crops and wild species for many purposes and using different methods to select the entries. The establishment of core collection involves the collation of existing data on the accessions within a collection, the grouping of accessions with characteristics in common and the selection of an appropriate sample from each group. The core collection methodology can also be applied to make cross-sections of any set of germplasm accessions, or to create bulk populations with the intention of increasing the usefulness of the collections. It can serve as a valuable aid, as an initial starting material, for initiating germplasm enhancement or pre-breeding activities.

5.4. Focused identification of germplasm strategy (FIGS)

FIGS represents a new and pragmatic approach to the identification of useful adaptive traits within landrace and wild germplasm collections that have adequate passport data associated with them (Street et al. 2006). In some cases, FIGS has proved exceedingly successful in identifying useful traits, allelic variation, new genes and seemingly completely new sources of resistance from relatively small subsets (smaller than core sets) of collections representing not more than 3% of the total collection (Mackay 1990; El Bouhssini and Nachit 2000; Street et al. 2006). Further refinement of FIGS will entail utilization of more comprehensive global databases, more sophisticated environmental modeling, inclusion of non geo-referenced accessions, and the use of different classes of information such as characterization/evaluation data, expert opinion, traditional knowledge and molecular data. Research is currently underway to compare the utility of the FIGS approach to the much cited core collection method (Kaur et al. 2008). It is hypothesized here that while the core collection approach is a useful method to capture and measure diversity within a small amount of germplasm, FIGS may well be a straight forward and efficient method of capturing specific adaptive traits from large and combined collections (Paillard et al. 2000; Street et al. 2006). Further, FIGS is entirely focused on the specific needs of the users and is size-flexible depending on the resources available for evaluation. Utilizing expanding global plant genetic resource databases, FIGS, coupled with the potential of eco-tilling (Comai et al. 2004) offers an exciting new development that will greatly facilitate the efficiency and effectiveness of mining genes from germplasm being conserved in the genebanks.

6. Making agrobiodiversity an integral part of rural development

There is little awareness among the various international development initiatives of the close relationship between climate change and food security and the role agrobiodiversity has to play in enhancing food security (Kotschi 2006). This relates to: the programs to achieve the Millennium Development Goals (MDGs), the National Adaptation Plans for Action (NAPAs) by the United Nations Framework Convention on Climate Change (CBD 2005) and others. Adaptation to climate change in agriculture - if discussed at all - deals mainly with improved water management (in view of more frequent drought and flooding events). Agrobiodiversity - although being a fundamental resource for adaptation - is often forgotten. Instead, it must become imperative to manage agrobiodiversity in a sustainable way and to use it systematically to cope with the coming environmental challenges.

The following aspects deserve consideration: (i) Stronger coordination is needed between main global programs such as the United Nations Framework Convention on Climate Change, the Convention of Biodiversity, and the International Treaty on Plant Genetic Resources for Food and Agriculture (CBD 2003 and 2005); (ii) Agrobiodiversity conservation be made a basic component of adaptation strategies to climate change; (iii) Programs that manage agricultural genetic resources should re-orient their strategies; formal institutional systems based on gene banks (*ex situ* conservation) must be broadened to an integrated management system that includes the farmer-based (*in situ*) conservation on-farm (Almekinders 2003), and (iv) The *in situ* conservation of agricultural biodiversity must be made an integral part of agricultural development and be supplemented by *ex situ* conservation; climate change-induced environmental stress may go beyond the reach of adaptation but the *in situ* approach offers a great chance to shape a future worth living (Kotschi 2006).

7. The challenges of breeding for climate change

The challenges of breeding for climate change are based around four broad sets of relationships that have been observed and measured in the field in several regions: (i) connection between temperature increases and reductions in the length of the growing season (time to maturity); (ii) connection of the changes in temperature and precipitation changes with pest, disease, and weed populations; (iii) differences in drought tolerance among crops, and (iv) interactions of multiple phenotypic changes in response to elevated greenhouse gas concentrations. In general, the understanding of abiotic interactions is better than biotic interactions (pest/pathogens) in the context of climate variability and climate change. Plant biologists typically work on one trait at a time (e.g., aspects of drought tolerance). With simultaneous changes in temperature, precipitation, CO_2 fertilization, and pest/pathogen dynamics, the breeding challenge will be enormous. Integrated research will be needed in the broader field of crop improvement and in the assessment of the production chain from geneticists to consumers. Basic research on individual traits will be necessary but not sufficient for crop adaptation to climate change. Useful traits will need to be "stacked" if new cultivars are to be successful in adapting to the multivariate changes predicted by the climate change models.

8. Breeding for drought and heat tolerance in major cereals

Several presentations, from both public and private sector participants, in the Balagio Conference (Lobell 2009) reviewed recent efforts at developing crops with improved drought and heat tolerance. It was noted that cultivars with improved performance under abiotic stress may exhibit sub-optimal yields when grown in stress-free environments. This tradeoff is not universal to all traits, and the goal of most current activities is to identify cultivars that out-perform both with and without stress. Yield tradeoffs are an impediment to the release of stress tolerant lines, for both economic and institutional reasons. Economically, farmers often make most of their money in high-yielding years, and are unwilling to sacrifice performance in these years to slightly improved yields in harsh years. Institutionally, most varieties are developed, tested, released and demonstrated in optimally managed trials. This is also the case in most stressful or resource constrained countries and regions where only a very small proportion of the farmers achieve those kinds of yield levels. Results from trials conducted under stress conditions are often discarded because results are more variable. It was suggested that in regions with frequent stress, paired demonstration plots - where varieties are grown both under recommended management practices and under farmer representative input conditions – would help to clarify the tradeoffs for farmers and possibly promote the adoption of more stress-tolerant cultivars. Also variety release authorities need to be conscious that variety releases based on trials grown under high yield potential conditions are inappropriate if the majority of farmers would grow their crops under more stressful conditions.

Drought has received far more attention than heat stress for all crops and in both public and private sectors. There are good reasons for this, namely that drought is perceived as a more important constraint on yields in current climate. Progress has been promising in recent years in many crops, particularly maize, because of the better control of stress levels in the managed drought trials in the field. CIMMYT in Africa achieved 15-20% yield gains in the hybrids by this method over the hybrids developed by breeding programs that did not use managed drought stress. Private seed companies have also adopted the managed stress trial approach in breeding and have reported significant progress.

Less work on maize has focused on heat as compared to rice and wheat, because as a C_4 crop maize can thrive better under higher temperatures. The importance of heat stress may have been underestimated for maize given that results presented at the Bellagio showed maize yields to decrease proportionate to the increase in days with temperatures exceeding 30^{o}C. Improvement of crop varieties, through a combination of breeding and biotechnology, combined with improved agronomy offered opportunity for achieving most success. Agronomic advances include conservation agriculture, based on reduced tillage and permanent soil cover, and rainwater harvesting. There are likely important interactions between agronomy and genotypes, and therefore testing varieties under a range of management systems could improve the eventual performance of the cropping system in drought conditions.

A major concern for adaptation through crop breeding is whether the biotic stresses will become more severe or widespread in a new climate, and whether abiotic stresses will interact with them. For example, hot conditions could favour certain diseases, weeds or pests, and drought or heat stressed crops could be more susceptible to disease. Yet progress on this topic has been slow, in part because of the complex nature of pest and disease responses, but also because of a lack of effective communication across disciplines. The climate community, for instance, understands very little about which specific variables are needed to predict pest and disease response.

The field studies looking at the genetic variation under future climates are rather limited. Most trials on the impact of heat and increased CO_2 levels examine distinct stages in the greenhouse and rarely look at the performance over an entire season or larger number of genotypes. Potential contributions from native genetic variation to securing crop production in future climates are hence little known. Efforts on improvement for abiotic stresses in cereals may hold important lessons for the improvement of less important crops (e.g., the next ten most important sources of calories). Bringing together scientists working on major and minor crops could thus help.

Although improved yields are likely to benefit farmers, the overall goal of adaptation should be to ensure that livelihoods, not necessarily just yields, are improved. This distinction may be important especially as markets develop for aspects of agricultural systems other than yields. For example, bioenergy markets are rapidly developing in many areas and may provide opportunities to generate income from crop residues, or dedicated biomass crops. Simultaneously, efforts to mitigate greenhouse gases have spawned markets for carbon credits, whereby farmers could receive money for preserving soil carbon or reducing methane and nitrous oxide emissions. Whether these would change the adaptation strategies from those that focus only on yields remains to be seen, but is a topic worthy of more focused attention.

9. Global search for food crops with traits to withstand climate change

A global search has begun for food crops with traits that are able to withstand changes to the climate. A project, co-ordinated by the Global Crop Diversity Trust, is searching national seed banks for "climate proof" varieties, including maize and rice. The team will screen seeds for natural resistance to extreme events, such as floods, droughts or temperature swings. Once the genetic profiles which confer resistance to drought, flooding and/or high temperatures have been found in one species of a food plant family it would seem sensible to attempt to insert these genes into related species rather than do it by conventional breeding techniques which would take longer to get the required new strain. Unfortunately however, some organisations are opposed to all research in the area of genetic transformation.

10. Roots of the second green revolution: breeding crops with better root systems

Cultivars with improved root systems would be able to explore the soil and acquire water and nutrients better than the normal ones. Indeed, there is large genetic variation for root traits. Traits that determine the shape of the root system, or *root architecture*, are especially important for exploration of different soil layers. Varieties also differ in their ability to solubilize nutrients in the soil through root exudates, and in the metabolic energy that is needed to grow and maintain root tissue. With a better understanding of these traits, it would be possible to develop new crop cultivars more efficient in the utilization of scarce soil resources.

With funding from the USAID Pulse CRSP and other sources, a team of plant nutritionists, agronomists, plant breeders, and socio-economists are working together to harness root traits in developing new common bean varieties with better yield in the dry, low-phosphorus soils common to many bean production regions of the tropics (Lynch 2009). Research at Penn State has identified specific root traits that improve phosphorus and water acquisition. In collaboration with bean geneticists at CIAT, the genetic control of these traits is being characterized to assist breeding efforts. Bean breeders at the Escuela Agricola Panamericana- Zamorano in Honduras and at IIAM in Mozambique are using this information to develop bean varieties with superior root systems in combination with other useful traits such as disease resistance and grain quality. The effect of the new varieties on the productivity of regional cropping systems is being evaluated by agronomic research at IIAM. Finally, the possible impacts of new stress-tolerant varieties on food security in local communities in Mozambique is being evaluated by a socioeconomic group at Penn State. Thus, this multidisciplinary team is making good progress.

Progress so far indicates that it is indeed possible to breed crops with better yield in poor soils by selecting for superior root systems. This approach is promising for resource-poor farmers in many developing countries, where yields are limited by drought and low soil fertility. This approach is also promising in developed countries such as the USA, where reducing the water and fertilizer requirements of agriculture is of growing importance given increasing fuel costs and global climate change.

11. Can crops be climate-proofed?

Climate change is making crop scientists review their research agenda. Until now, their main focus was on improving yields. But with successive Intergovermental Panel on Climate Change (IPCC) reports warning that increased droughts and floods will shift crop systems, 'climate-proofing' of crops has become crucial. The Consultative Group on

International Agricultural Research (CGIAR) institutes are now investigating how to make crops more resilient to environment stresses (Padma 2008).

Rice is most vulnerable to global warming. Studies worldwide show that rising carbon dioxide levels may initially increase growth, but the benefit is temporary. Rising temperatures make rice spikelets sterile, and grain yields will fall. 'Rice and Climate Change Consortium' at the International Rice Research Institute (IRRI) in the Philippines aims at breeding rice that can survive climate change; plants that can tolerate higher temperatures and/or flooding, that flower in the mornings before temperatures rise, and that transpire more efficiently.

Drought is also a big concern for the International Maize and Wheat Improvement Centre (CIMMYT) in El Batan, Mexico. The IPCC predicts increasing drought-spell disasters for half of the developing world's wheat growing areas. CIMMYT is looking for drought tolerance in wild wheats and landraces. The centre is also teaming up with the Japan International Research Centre for Agricultural Sciences to map drought-tolerant genes in wheat and maize and use them in enhancing the adaptation to climate change through conventional breeding and biotechnological tools. Researchers are working on genetically engineered wheat containing the DREB gene of *Arabidopsis thaliana* that may confer tolerance to drought, salinity and low temperatures. CIMMYT is testing yields of genetically engineered plants with the DREB gene under varying water stress.

The International Centre for Research in Semi-Arid Tropics (ICRISAT) research strategy for 2007–2012 targets climate change issues in the short- and medium-to-longer term. ICRISAT is working to make millets, sorghum, pigeon pea and groundnut better adapted to major climate stresses and scientists there have already developed cultivars tolerant to heat, high soil temperatures, low and variable rainfall, and diseases. A better knowledge, however, is needed of the physiological basis of stress tolerance, wider gene pools, and more effective screening methods for useful genes.

CIAT is developing computer software to analyse future climate scenarios. Examples include 'MarkSim' to simulate daily weather for up to 100 years anywhere in the tropics, and 'Homologue' to compare climate and soil throughout the tropics.

The International Centre for Agricultural Research in the Dry Areas (ICARDA) has studied how areas in and around Egypt, Morocco and Sudan are coping with water scarcity in rainfed and irrigated grasslands, as well as traditional watershed management systems. The scientists are developing barley, durum and bread wheat, chickpeas faba bean, lathyrus and lentil cultivars that can withstand drought and thrive under extremes of temperatures.

This progress notwithstanding, the task ahead is tough. Historically, the average time between scientists beginning to hunt for useful traits and a new stable cultivar growing in farmers' fields has been 46 years.

12. Prospecting of novel genes and allele mining for abiotic stress tolerance in the Indian national program

India has a rich biodiversity. Characterisation and utilisation of this diversity is essential to meet the challenges of biotic and abiotic stresses under changing climate. A project recently initiated in the Indian national programs is a step forward in this direction. The long-term perspective of the project is to: (a) prospect novel genes, promoters and alleles for economically important traits using indigenous bioresources, (b) functionally validate the new genes in model systems and different genetic backgrounds, (c) transfer the validated genes and alleles to recipient species cutting across biological barriers, and (d) develop a group of scientists from various disciplines and institutions for undertaking research in genomics and its application for improvement of agricultural species. The project will specifically have four main objectives: (a) generation of genomic resource base to facilitate gene prospecting and allele mining, (b) prospecting for new genes and alleles for abiotic stress tolerance, (iii) functional validation of the identified genes in model plant systems, and (d) use of the identified genes/allele in genetic enhancement of target species.

The project will use the following innovations and strategies to achieve the above objectives: (a) high throughput genome-wide approach in genotyping using sequence based markers to discover new genes and alleles, (b) exploitation of natural adaptive mechanism for abiotic stress tolerance in diverse biological systems including microbes, plants, animals and fish, (c) utilization of expertise cutting across diverse biological sciences, and (d) design and use new algorithms in the area of statistical and computational genomics that would accelerate application of genomic technologies for utilization of genetic resources and enhancement of agricultural species. There will be involvement of expertise available in 36 different institutions of the country including ICAR institutes, state agricultural universities, central universities, and the Indian Institutes of Technology (IITs). The organisms from which genes will be sourced for abiotic stress tolerance are microbes particularly the extremophiles, rice, maize, *Sorghum, Lathyrus, Ziziphus, Cucumis, Vigna*, camel, goat, trout, catfish, and shrimp. The species chosen for prospecting genes and mining alleles are genetically and biologically diverse with varying resource base. Fortunately, plenty of genetic and genomic resources are available in some of these species such as rice and maize and a great deal of information is already generated internationally on the genetic variation in respect of the chosen traits in these crops. Therefore, there is a greater chance of success in meeting the objectives in these two species.

The present project will act as pilot for the second phase in which the resources generated and the experience gained are efficiently used. Possible overall impact of the project would include enhancement and stabilization of food production under changing global climate in long-term, greater precision in genetic improvement programs thereby increasing the capability of Indian agricultural research system to meet the challenges to productivity and its sustainability, better understanding, value addition and protection of indigenous biological wealth, and a core group of scientists to provide leadership in cutting edge research in the field of gene and allele prospecting.

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Role of dryland agrobiodiversity in adapting and mitigating the adverse effects of climate change

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Abstract

Central, West Asia and North Africa region, which encompasses major centers of diversity of many crops of global importance, is expected to suffer more from the adverse effects of climate change than other regions in the world. It is imperative therefore that plant breeding efforts focus on the production of high yielding varieties that are tolerant to higher temperatures and more frequent drought episodes associated with climate change. In this context, landraces and wild relatives of crop plants that are still found within prevailing traditional farming systems in the dry lands and mountainous regions are potential sources of useful genes for plant breeding. Unfortunately, because of the destruction of natural habitats, caused by urbanization, over-exploitation and agricultural encroachment, and by replacement of landraces with improved varieties as traditional farming systems are modernized, the region is in danger of losing valuable genetic material that has the potential to contribute to climate change solutions. While a wealth of genetic resources has been collected from the region and conserved in genebanks a thorough gap analysis is needed to identify areas in which native germplasm is still evolving under harsh conditions so that existing *ex situ* holding can be enriched by targeted seed collection missions. To facilitate the efficient and effective exploitation of large *ex situ* collections for climate change breeding a rational method is needed to select appropriate material from genebanks to screen for desirable traits. ICARDA in partnership with ARIs is developing a selection methodology, termed the 'Focused Identification of Germplasm Strategy' (FIGS), that uses detailed agro-climatic data and statistical models to develop tailor made trait specific subsets of germplasm for breeding programs. Once appropriate donor germplasm has been identified intensive pre-breeding activities are needed to introgress genes from landraces and wild relatives into improved genetic backgrounds. This paper presents ICARDA's strategy to promote *ex situ* and *in situ* conservation of dryland agrobiodiversity and its subsequent use in plant breeding efforts for dryland areas that will be affected by climate change.

Keywords: adaptation, conservation approaches, climate change, crop wild relatives, dryland agrobiodiversity, FIGS, landraces, pre-breeding.

1. Introduction

Land degradation, loss of agro-biodiversity and climate change were recognized at local, national and international levels as major inter-related challenges to sustainable development and food security (CBD 1992). This recognition has led to the signing of three binding international agreements - United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Convention to Combat Desertification (UNCCD), and the Convention on Biological Diversity (CBD). Further, the meeting in Johannesburg in 2002 highlighted the need for more efforts to meet targets for biodiversity conservation and the meeting in Copenhagen in 2009 reiterated the importance of reducing global warming.

Biodiversity loss is occurring at an alarming pace and is due mainly to anthropogenic factors including population increase, poverty, limited awareness of the importance of conserving biodiversity, and a lack of appropriate policies. In addition to these factors, a major new threat is climate change (Maxted et al. 1997), which is expected to bring about major shifts in biodiversity through reducing species richness, distribution, and genetic diversity within populations. Further, the distribution of species is expected to move upwards in altitudes and latitudes if current climate change trends persist.
Current scenarios suggest that dry areas could experience hotter and drier conditions, especially in

the West Asia and North Africa region (De-Pauw 2004). ICARDA scientists used GIS analysis of satellite images to identify five key hot spots that are vulnerable to climate change in the CWANA region. These areas suffer from resource degradation, periodic droughts, and occasional famines.

Climate change could also lead to rapid desertification that will negatively impact the food and feed producing capacity in affected areas thus increasing the vulnerability of rural communities. The livelihoods of local communities living under harsh conditions in the drylands have depended to a large extent on agricultural and pastoral activities and the communities have mainly capitalized on the adaptation of local agrobiodiversity (landraces, local breeds, native species, etc.) and associated local knowledge (Mazid et al. 2005). In this context it is suggested here that dryland agrobiodiversity will play a crucial role in adapting to and mitigating the adverse effects of climate change provided that holistic and integrated ecosystem management approaches are adopted that include community-based *in situ* conservation and methodologies that promote sustainable use. This assertion is supported by Peacock et al. (2003) who concluded that the use of native species is the best option to rehabilitate the degraded rangelands in the Arabian Peninsula region.

FAO's High-Level Conference on World Food Security: the Challenges of Climate Change and Bioenergy, held in 2008 (http://www.fao.org/foodclimate/expert/ en/) highlighted the essential contributions of the Plant Genetic Resources to sustainable intensification of agricultural production in the face of climate change. The conference concluded that national, regional and international programs should take into account the effects of climate change when developing strategies for the conservation and sustainable use of plant genetic resources for food and agriculture (PGRFA) both *ex situ* and *in situ*, and recommended more efforts on the latter (Maxted et al. 1997).

ICARDA,with a global mandate within the CGIAR system for agricultural development in non-tropical dry areas, has worked for 33 years to improve the livelihoods of resource-poor farming communities living in dry areas. The technologies deployed include a combination of breeding higher yielding drought and heat tolerant germplasm with improved stability, integrated pest management, and appropriate agricultural packages for the management of scarce water resources.

To underpin the breeding initiatives ICARDA's Genetic Resources Section conserves more than 134,000 accessions in its genebank. The collection includes a high proportion of landraces and native species collected from the dry areas of CWANA region, which encompasses the centers of diversity for cool season crops of global importance (ICARDA 2004; Damania 1994; Harlan 1992). Further, ICARDA, through the development of *in situ* conservation and integrated ecosystem management approaches, attempts to promote the dynamic conservation of the rich plant and livestock diversities in the area. This is of importance because ecotypes that have evolved under harsh conditions will be the most likely source of appropriate genes for adaptation to climate change.

Vavilov (1935), in his agro-ecological survey of important field crops, recognized that an important factor in plant variety improvement is "the correct choice of the starting material". One way to identify this "starting material", or candidate accessions, from *ex situ* collections is to use 'predictive' attributes that link environments to accessions, thereby exploiting their evolutionary relationships (Mackay 1990). Many accessions in the *ex situ* collections were from the environment in which they evolved over millenniums. Since the environment influences gene flow, natural selection and thus spatial/geographic differentiation, collection site environments can be used as an indicator for adaptive traits (Vavilov 1935; Lin et al. 1975; Spieth 1979). For example Paillard et al. (2000) reported that populations of winter wheat with the highest level of resistance to powdery mildew originated from locations where the powdery mildew pressure was high, due to environmental factors, while the reverse was true of populations originating from locations where the pressure was low. It follows that, if we know where an *ex situ* accession evolved (or has been present for a significant period of time) it should be possible to predict which adaptive traits will express variation based on the selection pressures exerted by each collection site environment. This approach to germplasm utilization for climate change breeding and utilization is being developed by the Genebank at ICARDA.

2. Assessment of status and threats to dryland agrobiodiversity

ICARDA conducted farmer surveys in 26 communities as well as botanic and eco-geographic surveys in 65 monitoring areas in the drylands and mountainous regions of Jordan, Lebanon, Palestine and Syria from 2000 to 2004 and again in 2009 in Syria. The results showed that agricultural activities are based on the use of landraces of field crops and fruit trees and on local small ruminant breeds (Mazid et al. 2005). Agricultural activities account for 32 to 58% of farm income while the remainder is gained from remittances, retirement benefits and non agricultural activities. This demonstrates the vulnerability of rural communities to the negative impacts of climate change on agriculture and puts in question the ability of agriculture alone to sustain the livelihoods of local communities in the dry and harsh environments (Table 1). For wild relatives and native range species in natural habitats, the eco-geographic surveys showed trends towards decreases in the distribution and density of local populations following continuous overgrazing, natural habitat destruction, and land reclamation for urbanization and agricultural purposes (Table 2) (Amri et al. 2005). Increase in forest fires was also noted in Syria and Jordan in recent years. The study also found that rangelands could provide only 20 to 45% of the feed needs of small ruminant herds in the four countries. It is expected that climate change will amplify the negative effects of these threats as the capacity of remaining plant populations to regenerate is reduced. These negative trends call for more coordinated efforts to conserve and manage the remaining biodiversity rich areas.

3. Collecting and conserving dryland agrobiodiversity

ICARDA, in collaboration with NARS, has collected a large number of accessions that are avail-

Table 1. Contribution of alternative sources to total household income by target area (%) in Jordan, Lebanon, Palestine and Syria.

Income source	Jordan		Lebanon		Palestine		Syria	
	Muwaqqar	Ajloun	Aarsal	Baalbek	Hebron	Jenin	Sweida	Al-Haffeh
Crops & fruit trees	1	38	19	38	22	31	34	34
Livestock products	20	7	5	7	4	7	6	3
Live animals	17	4	8	5	12	20	3	6
Total on-farm income	38	49	32	50	38	58	43	43
Off-farm (Agriculture)	3	3	4	2	2	4	1	1
Off-farm (Non-agriculture)	3	6	45	22	39	12	2	17
Government employment	54	39	10	11	12	17	12	39
Remittances (from outside)	2	3	0	1	0	0	6	0
Other sources	0	0	9	14	9	8	36	0
Total off-farm income	62	51	68	50	62	42	57	57

Table 2. Percent of total project sites of Jordan, Lebanon, Palestine and Syria as affected by different levels of degradation from various factors; assessment year was 2000.

Factors of degradation	None	Low	Medium	High
Introduced species	30.9	25.5	34.5	9.1
Overgrazing	1.8	14.5	40.0	43.6
Urbanization	78.2	14.5	5.5	1.8
Cut & carry	52.7	18.2	25.5	3.6
Fire	81.8	12.7	5.5	0.0
Quarries	96.4	0.0	0.0	3.6
Extended drought	18.2	23.6	38.2	20.0

able within its genebank and collaborating genebanks. ICARDA and its in-country collaborators have carried out some 115 collection missions in CWANA. However, more are needed to improve eco-geographic coverage and to target germplasm with specific attributes.

To sample populations with potential adaptation to droughts, extreme temperatures and with potential resistance to newly evolving pest and disease biotypes, gap analysis of current holdings has been introduced to guide future collection missions. This GIS based process uses agro-climatic and edaphic information layers, combined with geo-referenced accessions and herbaria, to identify collection site distribution gaps for a given species in terms of ecological zones. For example, the *Aegilops* species: *Ae. vavilovii, Ae. searsii, Ae. crassa* and *Ae. kotschi* are primarily found in dry areas while *Ae. tauschii*, used widely for the production of synthetic hexaploid wheat, is usually associated with more humid ecological zones, although there are reports from Pakistan, Syria, Iran and Afghanistan of some populations of *Ae. tauschii* adapted to dry conditions (Fig. 1). Thus, collecting missions need to be organized in the dry areas to enrich the holdings of *Ae. tauchii* before the remaining populations are lost.
This type of analysis is increasingly used by researchers to identify gaps in *ex situ* collections and to locate sites for *in situ* conservation (Guarino 1995; Bari et al. 1998, 2005; De-Pauw 2005). This approach was used to plan for a collection in 2008 that sampled wheat and barley landraces from Morocco oases known to experience particularly hot temperatures and winds.

4. *In situ*/on-farm conservation of dryland agrobiodiversity

Ex situ conservation needs to be complemented with *in situ*/on-farm conservation and sustainable utilization of agrobiodiversity. The agrobiodiversity is often confined to traditional farming systems in the drylands and mountainous areas. ICARDA, through the GEF-UNDP funded project 'Conservation and Sustainable Use of Dryland Agrobiodiversity in Jordan, Lebanon, Palestine and Syria', developed a holistic and community driven approach for promoting *in situ*/on-farm conservation of landraces and crop wild relatives of global importance as well as native range species. The approach is based on management plans that include technological, socio-economic, institutional and policy/legal options that promote sustainable livelihoods and empowerment of local communities (Fig 2).

Landraces are presumed to be adapted to harsh conditions and low input agriculture as well as

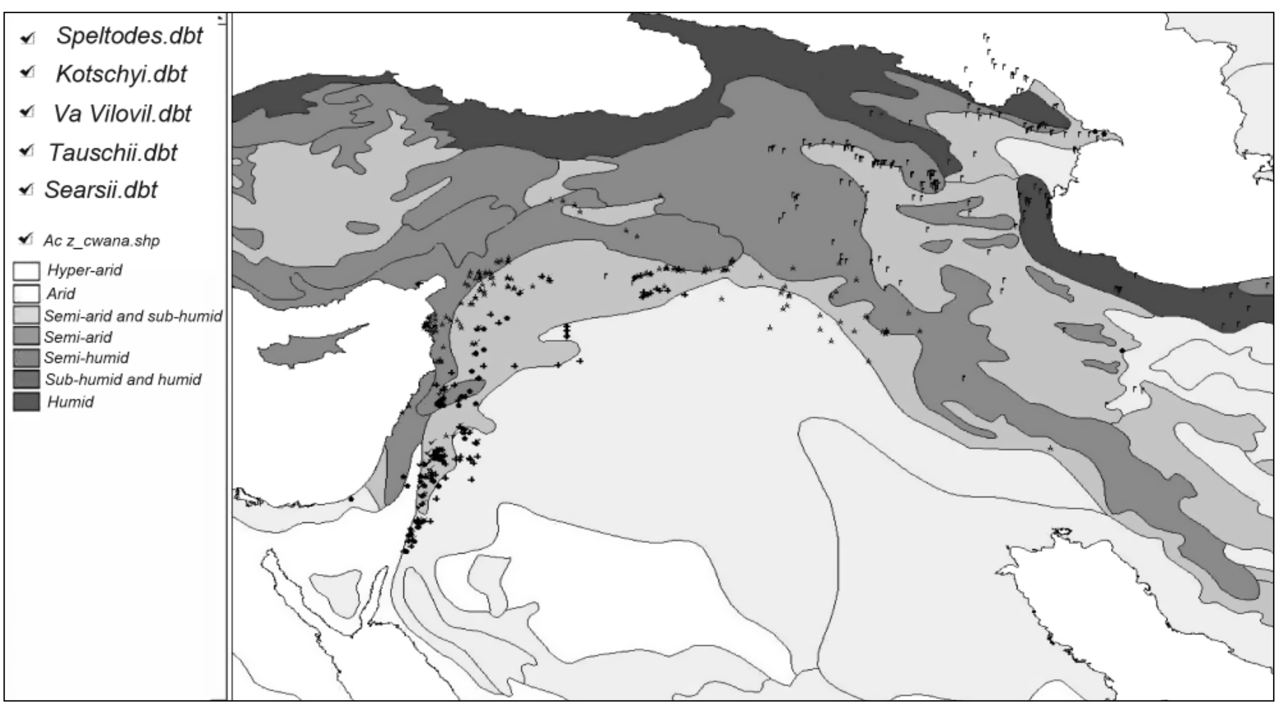

Figure 1. Distribution of some *Aegilops* species based on Aridity Index.

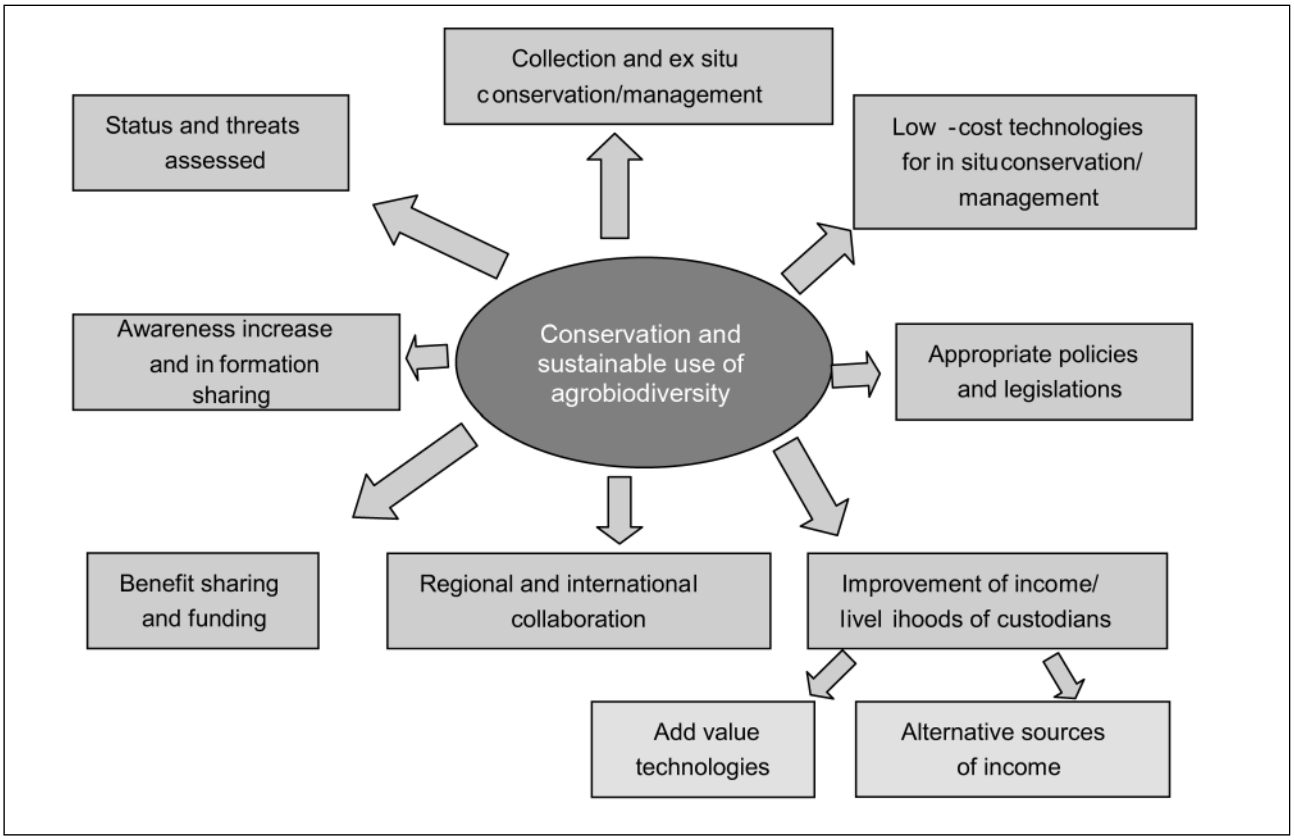

Figure 2. Elements of the strategy for promoting *in situ*/on-farm conservation of dryland agrobiodiversity.

having specific qualities that make them desirable to local communities. As such, they are an important component of the local agro-ecosystems. Technological options for improving the productivity of landraces include: participatory breeding to improve yield, seed cleaning and treatment through establishment of informal seed production and supply networks, and low-cost crop husbandry packages including water harvesting, conservation tillage and integrated pest management. Rehabilitation of degraded rangelands will have to be based on the use of native species coupled with water harvesting as well as the introduction of alternative feed sources such as feed blocks made out of farm wastes and agricultural byproducts.

The socio-economic options include income generation through adding value to agrobiodiversity products by improving the processing, packaging and labeling. In addition to this, new sources of income such as eco-tourism, growing medicinal plants and production of honey have to be explored. The success of the socio-economic options depends on access to markets and the level to which farmers can organize themselves to coordinate the marketing of their products.

Policy options include supporting agrobiodiversity rich areas with developmental projects, facilitating access to national and international markets, follow up on access to benefit sharing planned within the international conventions (CBD, UNCCD, UNCCC) and the International Treaty on Plant Genetic Resources for Food and Agriculture (IT-PGRFA). Further, policy makers need to establish protected areas within the major centers of diversity to ensure the survival of remaining populations of wild relatives of globally important crops. For the process to be sustainable and widely adopted, public awareness needs to be increased at all levels in addition to strengthened regional and international collaboration.

5. Targeting accessions for use (Focused Identification of Germplasm Strategy)

As breeders are challenged to produce new varieties that can deal with the complex impact of climate change they will increasingly look to genetic resource collections for novel genes. However, there are about six million germplasm accessions held in more than 1,300 genebanks around the globe (FAO 1997, 2007). Clearly, it is not feasible to screen the entire global collection of a given species when looking for specific traits. The question then is how does the germplasm user community rationally choose a subset of germplasm from this large global collection with a reasonable chance of finding the desired traits. Efficient and effective means of identifying candidate accessions with novel genetic variation for traits of importance to production are urgently required.

Based on the premise of the co-evolution between plants and biotic and abiotic factors, ICARDA's Genetic Resource Section, in collaboration with a number of advanced research institutions (ARIs), has been developing and testing a strategy, termed the Focused Identification of Germplasm Strategy (FIGS), to identify small best bet trait specific subsets of germplasm from global plant genetic resource collections. The FIGS approach aggregates commonly available accession level information (passport, characterization and evaluation data) with agro-ecological data (edaphic, climatic, etc) to predict where specific selection pressures may have occurred within *in situ* populations to identify candidates for the subsets.

The FIGS approach has successfully identified novel sources of resistance to Powdery mildew (Kaur et al. 2008), Sunn Pest, Russian wheat aphid, Hessian fly resistance as well as tolerance to salinity and drought in wheat (ICARDA under-publication).

While FIGS is the subject of ongoing research at ICARDA to improve its predictive ability, it is regularly being used to develop subsets of material in response to germplasm user requests. FIGS will be used to mine genetic resource collection for novel genes appropriate for adaptation to the adverse effects of climate change. However, the assessment of heat and drought tolerance of the parental germplasm and the segregating generations will require effective and precise phenotyping procedures.

6. The strength of pre-breeding

Genetic resource conservation needs to be linked to the utilisation either directly (e.g., to rehabilitate degraded natural and farming systems), or through the introgression of useful genes into improved varieties by pre-breeding. Pre-breeding involves the transfer of genes from species within any of the three genepools (infraspecific, interspecific and intergeneric) into parental germplasm that can be readily used in conventional breeding programs. Most pre-breeding programs transfer genes from wild relatives or wild distant species, which often requires specialized techniques and skills.

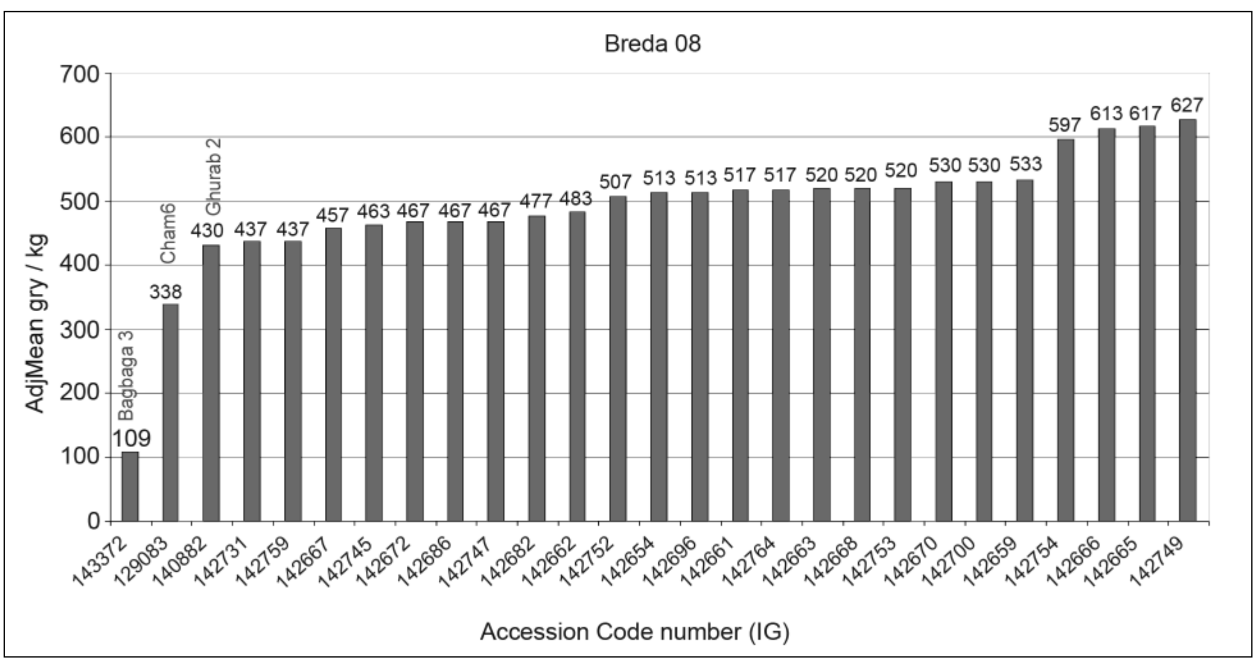

Figure 3. Grain yield (kg/ha) of lines derived from wild crosses and backcrosses with Cham 5 durum wheat compared to best available promising lines (Babagha 3 and Ghurab 2) evaluated under severe stress at Breda during 2007-08 season (164 mm of rain).

Table 3. Wild species used as sources to transfer valuable traits to bread wheat and durum wheat varieties.

Trait	Donor species
Leaf rust resistance	*T. baeoticum, Ae. speltoides*
Yellow rust resistance	*T. baeoticum, T. urartu, Ae. speltoides, T. dicoccoides*
Spetoria tricici	*T. dicoccoides, Ae. speltoides*
Russian wheat aphid	*T. baeoticum*
Hessian Fly	*Ae. tauschii*
Sunn pest at seedling stage	*T. baeoticum, T. urartu*
Spike productivity	*T. baeoticum, T. urartu, Ae. tauschii*
Plant height (short stature)	*T. urartu, Ae. tauschii*
Earliness	*T. urartu, T. dicoccoides*
Drought tolerance	*Ae. tauschii*
High productive tillering	*T. urartu*

Several wild species of wheat, mainly those with potential adaptation to extreme temperatures, drought and salinity have not yet been fully exploited. In this context, the ICARDA's Genetic Resources Unit initiated inter-specific crosses in 1994 using wild *Triticum* (*T. beooticum, T. monococcum, T. dicoccoides*) and *Aegilops* (*Ae. tauschii, Ae. speltoides*) species to improve bread and durum wheat. The lines derived from crosses with ten accessions of these species have shown high levels of resistance to major diseases and insects including Septoria, yellow rust, Russian wheat aphid, Hessian fly and Sunn pest at seedling stage (Table 3).

Some of these lines have also shown grain yields significantly higher than the best available checks under dry conditions as experienced in the 2007-08 season (Fig. 3). In the 2007-08 season, 200 accessions of *Ae. tauschii* were screened under severe drought conditions at Breda and Tel Hadya experiment stations in Syria. Eighteen accessions of *Ae. tauschii* and three accessions of *Ae. vavilovii* showed good levels of tolerance to drought and are being used in further interspecific crosses.

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Reviving beneficial genetic diversity in dryland agriculture - a key issue to mitigate climate change negative impacts

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Abstract

The unpredictable nature of climate change challenges most of the established agricultural practices. The concept of food security and yield stability must be addressed with regards to all possible agronomic solutions to future climatic instability. Evolutionary and participatory plant breeding methods are effective approaches to the agronomic problems associated with climate change. One of the main objectives of conventional breeding programs for self-pollinating cereal crops is to develop genetically uniform varieties. This genetic uniformity may not be appropriate for tackling the negative impact of environmental and climatic changes. Breeding for sustainability is a process of fitting cultivars to an environment instead of changing the growing environment (by using fertilizer, water, pesticides, etc.) to fit the developed cultivar. In participatory and evolutionary plant breeding methods, farmers' selection, working with natural selection on a genetically diverse population, will maximize adaptation to environments with specific stresses and also enhance resilience against climate change. Recognizing the negative impact of global warming and climatic change on cereal production in the rainfed conditions in Iran, to mitigate this impact by harnessing the genetic diversity, we have started a participatory and evolutionary plant breeding program on cereals in Kermanshah and Semnan provinces of Iran.

Keywords: cereals, climate change, evolutionary plant breeding, participatory plant breeding rainfed farming.

1. Introduction

In Iran and other developing countries farmers working under rainfed and low-input farming systems often grow cultivars developed through the conventional plant breeding program where selection takes place under high inputs of fertilizers and crop protection chemicals. In addition, these crops are selected in environments that often are not representative of farmer's local conditions. Under rainfed and low-input farming systems where the predictability of important variables is less certain than in conventional systems, there is great need for genetic diversity in a crop community to buffer against the risks of these variables. Under these farming systems, the field conditions vary from year to year and even within a village from farm to farm. Growing genetically uniform cultivars in these conditions causes yield instability.

The world's crop production at present is primarily constrained by several environmental stresses.

Drought, especially in low-input systems, is one of the most significant abiotic stresses, that causes huge variations in grain yield. Among the limitations in the conventional breeding is the fact that drought resistance and yield potential are mostly negatively correlated to each other, and as a consequence of the genetic complexity of drought resistance, the selection for physio-morphological traits associated with drought tolerance will not prove successful, and pyramiding all these traits in a single genotype is impossible. But it is possible that some of these traits get pyramided in a single genotype, providing tolerance against certain level of drought occurring in certain environment. A mixture of such genotypes, each with different sets of those traits, will have a wider range of drought tolerance genes and related traits which would buffer the population against any level of drought. The same concept is also true for developing sustained tolerance/resistance to other biotic and abiotic stresses where traits related to adaptation have not yet been identified.

The unpredictable nature of climate change challenges the long-term viability of many of our established agricultural practices. The concept of food security and yield stability must be addressed with regards to all possible agronomic solutions to future climatic instability (Murphy 2008) and in this regard, reviving the lost genetic diversity, one such solution, offers unique opportunity to find solution of the agronomic problems associated with climate change. Participatory and evolutionary plant breeding programs are effective and feasible approaches to help us in the important mandate of reviving crops genetic diversity.

2. Participatory plant breeding

Participatory approaches enable local people to contribute their valuable practical knowledge in regional agricultural development. In many of the examined cases of the participatory plant breeding (PPB), farmers test a larger number of varieties than is traditionally done during the adaptive or on-farm yield trials of conventional crop improvement research (Haghparast et al. 2009). By emphasizing the development of cultivars specifically adapted to a multitude of target environments defined according to the repeatability of genotype × locations interactions (Annicchiarico 2002; Annicchiarico et al. 2005; Singh et al. 2006), PPB is able to cope with the negative impact of climate changes by promoting crop genetic diversity. By emphasizing specific adaptation, PPB is also expected to be more capable than conventional plant breeding in addressing some of the specific problems that are common to many conventional breeding programs in developing countries (Ceccarelli et al. 2007) and also organic farming systems in developed countries (Dawson et al. 2008).

3. Dynamic preservation of crop species in gene banks

Conservation of genetic diversity for crop species is carried out by storing seeds or other propagating components of several thousand accessions per species in gene banks. With such static conservation we can preserve the genetic diversity present at the time of the collection (Frankel et al. 1995), but the preservation of crop species *per se* may be of limited utility if continuous adaptation is required for growth under a changing environment with respect to the biotic and abiotic stresses or climate (Simmonds 1962; Henry et al. 1991). Trying to mimic natural population processes, dynamic management (DM) of populations has been proposed to ensure crop genetic diversity to fit the future needs of plant breeding (Henry et al. 1991). This strategy for conservation of genetic resources aims at maintaining the evolutionary processes among a set of genetically diverse populations grown across generations in a network of different sites differing in climatic and biotic conditions. DM is expected to allow for adaptive changes within populations in response to local selection pressures, while simultaneously maintaining genetic variation on the whole. In Iranian national gene bank and other gene banks in the world, thousands of accessions of wheat and other crop species suitable for cultivation under dryland agriculture, including land races, are under static conservation, while the dryland farming is suffering from low genetic crop diversity, and consequent yield instability, in the face of abiotic stresses caused by global warming and climate change. A Persian proverb says, “preventing detriment means gaining profit”. To gain profit by reviving beneficial genetic diversity, the accessions of crops in gene bank must be managed dynamically for evolution under changing climate to gain crop species adapted to low-input systems in drylands. Therefore, it has been proposed that a mixture of crosses or of germplasm accessions of a certain crop be grown for generations in a network of different sites differing in climatic and biotic conditions (Ceccarelli 2009). Goldringer et al. (2006) studied heading time of six composite cross populations of wheat in the tenth generation under different vernalization and photoperiodic conditions and reported that the comparison of population differentiation indices obtained from molecular markers and from quantitative traits confirmed the role of natural selection in shaping genetic differentiation between the dynamic managed populations.

4. Evolutionary breeding

Harry Harlan began making composite cross populations from many diverse barley cultivars from around the world in 1920 (Harlan and Martini 1929). For example, composite cross II was a population developed by Harlan in 1929 using 30 cultivars crossed in all possible combinations. In an evolutionary breeding approach using these composite cross populations, Sunesen (1956) and Allard (1996) planted these populations each year, under standard agronomic conditions, and harvested them each year over a period of 50 years.

No artificial selection was conducted, but the populations were exposed to multiple environmental stresses and the resulting harvest often reflected the populations' response to pressure from natural selection. These pressures included multiple diseases, drought and high temperatures. Results from numerous studies on these populations have shown steady increases in grain yield and disease resistance over time and yield stability over diverse environmental conditions (Murphy 2008).

Suneson (1956), describing this "new" method of plant breeding, suggested that it is important to recognize the value of evolutionary fitness in plant breeding. Evolutionary change is based upon the interaction between populations and their environments, where environmental interactions include both abiotic and biotic conditions. Suneson (1956) described the process to involve assembly of seed stocks with diverse evolutionary origins, recombination by hybridization, the bulking of F1 progeny, and subsequent prolonged natural selection for mass sorting of the progeny in successive natural cropping environments. Therefore, this method of plant breeding moves away from the notion of strictly uniform crop populations and towards populations with a high level of heterogeneity.

A detailed quantitative analysis of a certain barley composite cross populations by Jain and Suneson (1956) showed that in spite of 98 to 99% self pollination in barley, a significant amount of genetic variability was maintained through heterozygote advantage and optimizing selection favoring intermediate phenotypes. It was argued that predominantly selfing species are clearly not devoid of the advantages of a genetic system allowing the maintenance and flow of genetic variability required for both immediate fitness and long term flexibility (Jain and Allard 1960; Jain and Suneson 1966). The population fitness, as measured by fecundity and agricultural productivity under several experimental setups, consistently showed a lower level of performance in the higher out breeding series and also did not seem to improve at any higher rate despite the increased recombination potential under enforced out breeding. Thus, the amounts of variability produced by rather low rates of natural outcrossing in the bulk-hybrid populations of barley are large enough to allow optimal rates of utilization under natural selection for adaptive improvement.

When Suneson (1956) brought up the issue of evolutionary plant breeding, he considered genetic buffer as a solution for yield instability in conditions with unpredictable variables; changing climate and global warming was not considered as a major global concern, but he predicted and proved the negative impact of crop homogeneity in heterogeneous environment.

5. Participatory plant breeding in Iran

In 2006, we started a PPB program for barley and bread wheat in two villages, Zamanabad and Nojoub in Sarfiriozabad, in Kermanshah province of Iran. The trials were conducted in the 2006-2007 cropping season following a detailed consultation with the farmers of the two communities organized by the staff of the Dryland Agriculture Research Sub-Institute (DARSI), CENESTA, ICARDA and the Provincial Agriculture Organization in Kermanshah. In the 2008-2009 cropping season, two more regions in Kermanshah province were added to this program and farmers along with breeders selected better genotypes compared to checks. The superior genotypes were planted in bigger plots in 2009-2010 cropping season along with the new genotypes. Farmers from other regions of Kermanshah province, who became aware of this program, requested to join the PPB program. Therefore, in 2009-2010 cropping season the program extended to 6 locations in the cold region and 2 locations in the warm area of Kermanshah province (Table 1) and we planted local bread and durum wheat genotypes from different locations of Iran, seeds of which were obtained from the ICARDA gene bank and multiplied in 2008-2009 at Sararood station in Kermanshah, Iran.

6. Evolutionary plant breeding (EPB) in Iran

Since 2008-2009 we started EPB with barley at different sites in Kermanshah and Semnan provinces (Table 1). The material consisted of a mixture of nearly 1600 F2 populations obtained from ICARDA. This mixture was divided into three sets of 4 kg each and given to two farmers from Dalahoo and Rvansar regions in Kermanshah province, and one farmer from Garmsar region in Semnan province. The mixture was planted on 250 m^2 of land under rainfed condition in Kermanshah and under irrigated condition in Semnan. Farmers were asked to grow and harvest this material year after year in the same condition in which they intended to grow their crop cultivars in the future. Farmers are expected to give to the scientists 4 kg of seed to be stored as a backup, grow 4 kg in the same condition in their field and share the rest with other farmers to grow on their farms. Every year, or at longer intervals, and as the population evolves and new, better adapted, recombinants appear, artificial selection can be applied to extract individual components or sub populations. These can be used by farmers in their commercial farms, and breeders can select individual plants out of that for the next crossing program or multiplication as pure individual genotypes while the original population continues to evolve. These genotypes can be maintained in gene banks also and remixed in the case of losing the final evolved mixtures.

In the cropping season 2009-2010, we kept up barley EPB by sharing 4 kg seed of last season EPB to new farmers in the same region and 15 other new regions in these two provinces and one location in Charmahal Bakhtiari province (Table 1). Farmers, participating in this program in the first year, saw superior performance of this buffered mixture in their harsh rainfed condition and got more enthusiastic to keep up evolutionary plant breeding. We also started a bread wheat EPB using the mixture of wheat segregating population obtained from the breeding program of Dryland Agricultural Research Sub-Institute (DARSI), Kermanshah, Iran.

Table 1. Sites of participatory (PPB) and evolutionary (EPB) plant breeding in Iran in the 2009-2010 cropping season.

Kermanshah province		
EPB sites	**PPB sites**	**Both EPB and PPB sites**
Cold region	**Cold region**	**Semnan province**
Sarfiroz Abad, Kharegaw	Sarfiroz Abad, Kharegaw	Garmsar, Malijan
Dalatoo, Telesm	Dalatoo, Telesm	Garmsar, Chartaghi
Ravansar, Borhanedin	Ravansar, Borhanedin	Garmsar, Goroh-e-Ghods
Sahne, Elahiye	Sahne, Elahiye	Garmsar, Mahdi Abad
Javanrood, Ban Golan	Bisotoon, Gorgavand	Damghan, Dehmola
Homeil, Zafaran	Homeil, Zafaran	Kalposh, Soda Ghalan
	Javanrood, Ban Golan	Garmsar, Naroohe
Warm region	**Warm region**	**Charmahal-e-Bakhtiary province**
Ghasr-e-shirin, Nasr Abad	Ghasr-e-shirin, Nasr Abad	Shahre Kord, Chamkhoram
Gilan-e-gharb, Behabad-e-saleh		

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Plant breeding and climate change

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Abstract

Climate change is now unequivocal, particularly in terms of increasing temperature, increasing CO_2 concentration, widespread melting of snow and ice, and rising global average sea level, while the increase in the frequency of drought is very likely but not as certain. Yet, climate changes are not new and some of them have had dramatic impacts such as the appearance of leaves about 400 million years ago as a response to a drastic decrease of CO_2 concentration, the birth of Agriculture due to the end of the last ice age about 11,000 years ago and the collapse of civilizations due to the late Holocene droughts between 5,000 and 1,000 years ago. The climate change which is occurring now will have – and is already having – an adverse effect on food production and food quality with the poorest farmers and the poorest countries most at risk. The adverse effect is either a consequence of the expected or likely increased frequency of some abiotic stresses such as heat and drought and of the increased frequency of biotic stresses (pests and diseases). In addition, climate change is also expected to cause losses of biodiversity, mainly in more marginal environments. Plant breeding has been always addressing both abiotic and biotic stresses and strategies of adaptation to climate changes may include a more accurate matching of phenology to moisture availability using photoperiod-temperature response, increased access to a suite of varieties with different durations to escape or avoid predictable occurrences of stress at critical periods in crop life cycles, improved water use efficiency, and a re-emphasis on population breeding, in the form of evolutionary participatory plant breeding to provide a buffer against increasing unpredictability. ICARDA has recently started evolutionary participatory programs in barley and durum wheat. These measures will go hand in hand with breeding for resistance to biotic stresses, and with an efficient system of variety delivery to farmers.

Keywords: adaptation to climate change, drought, evolutionary plant breeding, population breeding.

1. Climatic changes today

Today nobody questions whether climate changes are occurring or not, and the discussion has shifted from whether they are happening to what to do about them. The most recent evidence from the Fourth Assessment Report on Climate Change of the Intergovernmental Panel on Climate Change (IPCC 2007) indicates that the warming of the climate system is unequivocal, as it is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Quoting from the report:

- "eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850)"
- The temperature increase is widespread over the globe, and is greater at higher northern latitudes. Land regions have warmed faster than the oceans.
- Rising sea level is consistent with warming.

Global average sea level has risen since 1961 at an average rate of 1.8 mm/yr and since 1993 at 3.1 mm/yr, with contributions from thermal expansion, melting glaciers and ice caps, and the polar ice sheets.
- Observed decreases in snow and ice extent are also consistent with warming. Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7% per decade, with larger decreases in summer of 7.4% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres."

It is also very likely that over the past 50 years cold days, cold nights and frosts have become less frequent over most land areas, and hot days and hot nights have become more frequent, and it is likely that heat waves have become more frequent over most land areas, the frequency of heavy precipitation events has increased over most areas, and since 1975 the incidence of extreme high sea level has increased worldwide. There is also observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, with limited evidence of increases elsewhere. There is no clear trend in the annual numbers of tropical cyclones but there is evidence of increased intensity.

Changes in snow, ice and frozen ground have with high confidence increased the number and size of glacial lakes, increased ground instability in mountain and other permafrost regions, and led to changes in some Arctic and Antarctic ecosystems (Walker 2007). The projections to year 2100 indicate that CO_2 emission is expected to increase by 400% and CO_2 atmospheric concentration is expected to increase by 100% (Fig. 1).

Some studies have predicted increasingly severe future impacts with potentially high extinction rates in the natural systems around the world (Williams et al. 2003; Thomas et al. 2005).

2. Climatic changes in history

Even though climate changes are one of the major current global concerns, they are not new. Several climate changes occurred before, with dramatic consequences. Among these is the decrease in CO_2 content which took place 350 million years ago and which is considered to be responsible for the appearance of leaves – the first plants were leafless and it took about 40-50 million years for the leaves to appear (Beerling et al. 2001).

The second climatic change is that induced by perhaps the most massive volcanic eruptions in Earth's history which took place in Siberia when up to 4 million cubic kilometers of lava erupted onto the surface. The remnants of that eruption cover today an area of 5 million square kilometers. This massive eruption caused, directly or indirectly, through the formation of organohalogens, a worldwide depletion of the ozone layer. The consequent burst of ultraviolet radiation explains why the peak eruptions phase coincides with the timing of the mass extinction that wiped out 95% of all species.

The third major climate change was the end of the Ice Age (between 13 and 11,500 BC) with the main consequence that much of the Earth was subject to long dry seasons. This created favorable conditions for annual plants, which can survive the dry seasons either as dormant seeds or as tubers, and eventually agriculture started, as we

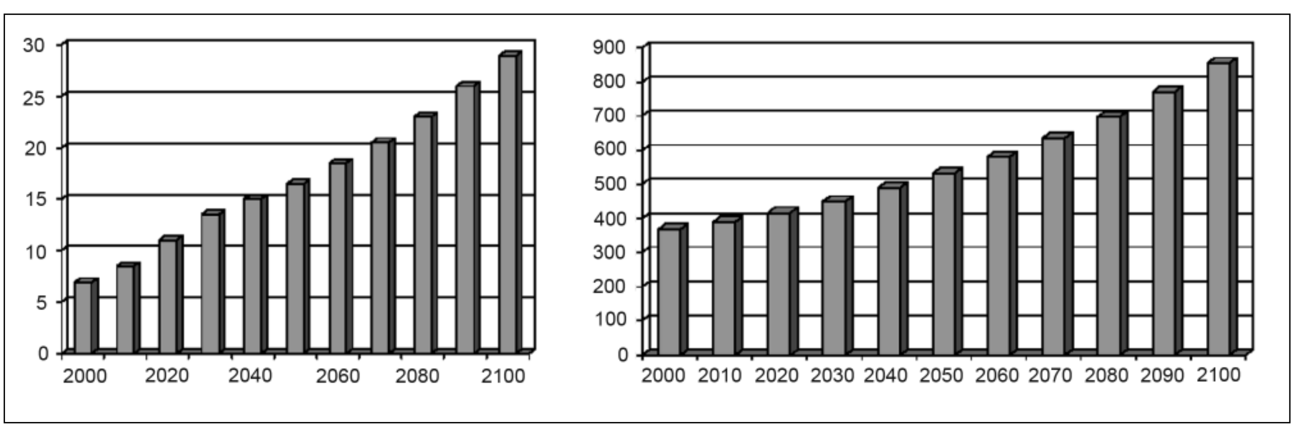

Figure 1. Projected CO_2 emission in billion tons carbon equivalent (left) and atmospheric CO_2 concentration in parts per million (right).

know today, in that area of the Near East known as the Fertile Crescent around 9,000 BC, and soon after, in other areas.

The fourth climatic change is the so called Holocene flooding which took place about 9,000 years ago and is now believed to be associated with the final collapse of the Ice Sheet resulting in a global sea level rise by up to 1.4 m (Turney and Brown 2007). Land lost from rising sea levels drove mass migration to the North West and this could explain how domesticated plants and animals, which by then had already reached modern Greece, started moving towards the Balkans and eventually into Europe.

During the last 5,000 years drought, or more generally limited water availability, has historically been the main factor limiting crop production. Water availability has been associated with the rise of multiple civilizations while drought has caused the collapse of empires and societies, such as the Akkadian Empire (Mesopotamia, ca. 4200 calendar yr B.P.), the Classic Maya (Yucatan Peninsula, ca. 1200 calendar yr B.P.), the Moche IV–V Transformation (coastal Peru, ca. 1500 calendar yr B.P.) (de Menocal 2001) and the early bronze society in the southern part of the Fertile Crescent (Rosen 1990).

3. How do people respond to climatic changes?

Although the debate about climate changes is relatively recent, people, for example in Africa have been adapting to climate changes for thousands of years. In general, people seem to have adapted best when working as a community rather than as individuals. The four main strategies of adaptation have been a) changes in agricultural practices, b) formation of social networks, c) embarking in commercial projects, such as investing in livestock, and d) seeking work in distant areas: the first three of these strategies rely on people working together to improve their community (Giles 2007).

In continuous coping with extreme weather events and climatic variability, farmers living in harsh environments in Africa, Asia and Latin America have developed and/or inherited complex farming systems that have the potential to bring solutions to many uncertainties facing humanity in an era of climate change (Altieri and Koohafkan 2003).

These systems have been managed in ingenious ways, allowing small farming families to meet their subsistence needs in the midst of environmental variability without depending much on modern agricultural technologies (Denevan 1995). These systems still to be found throughout the world, covering some 5 million hectares, are of global importance to food and agriculture, and are based on the cultivation of a diversity of crops and varieties in time and space that have allowed traditional farmers to avert risks and maximize harvest security in uncertain and marginal environments, under low levels of technology and with limited environmental impact (Altieri and Koohafkan 2003). One of the salient features of the traditional farming systems is their high degree of biodiversity, in particular the plant diversity in the form of poly-cultures and/or agro-forestry patterns. This strategy of minimizing risk by planting several species and varieties of crops is more adaptable to weather events, climate variability and change and resistant to adverse effects of pests and diseases, and at the same time it stabilizes yields over the long term, promotes diet diversity and maximizes returns even with low levels of technology and limited resources (Altieri and Koohafkan 2003). The term autonomous adaptation is used to define responses that will be implemented by individual farmers, rural communities and/or farmers' organizations, depending on perceived or real climate change in the coming decades, and without

Table 1. Expected number of undernourished in millions, incorporating the effect of climate.

	1990	2020	2050	2080	2080/1990
Developing countries	885	772	579	554	0.6
Asia, Developing	659	390	123	73	0.1
Sub-Saharan Africa	138	273	359	410	3.0
Latin America	54	53	40	23	0.4
Middle East and North Africa	33	55	56	48	1.5

intervention and/or co-ordination by regional and national governments and international agreements. To this end, pressure to cultivate marginal land, or to adopt unsustainable cultivation practices as yields drop, may increase land degradation and endanger the biodiversity of both wild and domestic species, possibly jeopardizing future ability to respond to increasing climate risk later in the century.

One of the options for autonomous adaptation includes the adoption of varieties/species with increased resistance to heat shock and drought (Bates et al. 2008).

4. Climatic changes, food and agriculture

Using the results from formal economic models, it is estimated (Stern 2005) that in the absence of effective counteraction, the overall costs and risks of climate change will be equivalent to losing at least 5 percent of global gross domestic product (GDP) each year. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20 percent of GDP or more, with a disproportionate burden and increased risk of famine on the poorest countries (Altieri and Koohafkan 2003).

The majority of the world's rural poor, about 370 million of the poorest, live in areas that are resource-poor, highly heterogeneous and risk-prone. The worst poverty is often located in arid or semiarid zones, and in mountains and hills that are ecologically vulnerable (Conway 1997). In many countries, more people, particularly those at lower income levels, are now forced to live in marginal areas (i.e., floodplains, exposed hillsides, arid or semiarid lands), putting them at risk from the negative impacts of climate variability and change.

Climatic changes are predicted to have adverse impacts on food production, food quality and food security. One of the most recent predictions (Tubiello and Fischer 2007) is that by the year 2080 the number of undernourished people will increase by 1.5 times in the Middle East and North Africa and by 3 times in Sub-Saharan Africa compared to 1990 (Table 1).
Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce crop yields while encouraging weed, disease and pest proliferation. Changes in precipitation patterns increase the likelihood of short-run crop failures and long-run production declines. Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security (Nelson et al. 2009).

Food insecurity is likely to increase under climate change, unless early warning systems and development programs are used more effectively (Brown and Funk 2008). Today, millions of hungry people subsist on what they produce. If climate change reduces production while populations increase, there is likely to be more hunger. Lobell et al. (2008) showed that increasing temperatures and declining precipitation over semiarid regions are likely to reduce yields for corn, wheat, rice, and other primary crops in the next two decades. These changes could have a substantial negative impact on global food security.

5. How do crops respond to climatic changes?

Adapting crops to climatic changes has become an urgent challenge which requires some knowledge on how crops respond to those changes.
In fact plants have responded to increasing CO_2 concentration from pre-industrial to modern times by decreasing stomatal density – reversing the change described earlier which led to the appearance of leaves – as shown by the analysis of specimens collected from herbaria over the past 200 years (Woodward 1987). In *Arabidopsis thaliana* the gene *HIC* (High Carbon Dioxide) prevents changes in the number of stomata in response to increasing CO_2 concentration (Gray et al. 2000); mutant *hic* plants exhibit up to 42% increase in stomatal density in response to a doubling of CO_2. The implication is that the response of the stomatal density to increasing CO_2 concentration in many plant species is now close to saturation (Serna and Fenoll 2000). Stomatal density varies widely within species: for example in barley it varies from 39 to 98 stomata/mm^2 (Miskin and Rasmusson 1970) suggesting that the crop has a fairly good possibility of adaptation.

It is now fairly well known how plants respond to increases in CO_2 concentration, which has both direct and indirect effects on crops. Direct effects (also known as CO_2-fertilisation effects) are those affecting the crops by the presence of CO_2 in ambient air, which is currently sub-optimal for C_3 type plants like wheat and barley. In fact, in C_3 plants, mesophyll cells containing ribulose-1,5-bisphosphate carboxylase-oxygenase (RuBisCO) are in direct contact with the intercellular air space that is connected to the atmosphere via stomatal pores in the epidermis. Hence, in C_3 crops, rising CO_2 increases net photosynthetic CO_2 uptake because RuBisCO is not CO_2-saturated in today's atmosphere and because CO_2 inhibits the competing oxygenation reaction leading to photorespiration. CO_2-fertilisation effects include increase of photosynthetic rate, reduction of transpiration rate through decreased stomatal conductance, higher water use efficiency (WUE), and lower probability of water stress occurrence. As a consequence crop growth and biomass production should increase up to 30% for C_3 plants at doubled ambient CO_2 – other experiments show 10–20% biomass increase under double CO_2 conditions. In theory, at 25ºC, an increase in CO_2 from the current 380 ppm to that of 550 ppm, projected for the year 2050, would increase photosynthesis by 38% in C_3 plants. In C_4 plants, such as maize and sorghum, RuBis CO is localized in the bundle sheath cells in which CO_2 concentration is three to six times higher than atmospheric CO_2. This concentration is sufficient to saturate RuBis CO and in theory would prevent any increase in CO_2 uptake with rising CO_2. However, even in C_4 plants, an increase in water use efficiency via a reduction in stomatal conductance caused by increased CO_2 may still increase yield (Long et al. 2006).

However, the estimates of the CO_2-fertilisation have been derived from enclosure studies conducted in the 1980s (Kimball 1983; Cure and Acock 1986; Allen et al. 1987), and today they appear to be overestimated (Long et al. 2006). In fact, free-air concentration enrichment (FACE) experiments, representing the best simulation of the future elevated CO_2 concentration, give much lower (about 50% lower) estimates of increased yields due to CO_2-fertilisation (Table 2).

Indirect effects (also known as the weather effects) are the effects of solar radiation, precipitation and air temperature and, keeping management the same, cereals yields typically decrease with increasing temperatures and increase with increased solar radiation. If water is limited, yields eventually decrease because of higher evapotranspiration. Precipitation will obviously have a positive effect when it reduces water stress but can also have a negative effect such as, for example, by causing water logging.

In addition to CO_2, also nitrogen (N) deposition is expected to increase further (IPCC 2007) and it is known that increasing N supply frequently results in declining species diversity (Clark and Tilman 2008). In a long-term open-air experiment, grassland assemblages planted with 16 species were

Table 2. Percentage increases in yield, biomass and photosynthesis of crops grown at elevated CO_2 (550 ppm) in enclosure studies versus FACE (Free-Air Concentration Enrichment) experiments (Long et al. 2006).

Source	Rice	Wheat	Soybean	C4 crops
Yield				
Kimball (1983)	19	28	21	-
Cure and Acock (1986)	11	19	22	27
Allen et al. (1987)	-	-	26	-
Enclosure studies	-	31	32	18
FACE studies	12	13	14	0^*
Biomass				
Cure and Acock (1986)	21	24	30	8
Allen et al. (1987)	-	-	35	-
FACE studies	13	10	25	0^*
Photosynthesis				
Cure and Acock (1986)	35	21	32	4
FACE studies	9	13	19	6

grown under all combinations of ambient and elevated CO_2 and ambient and elevated N. Over 10 years, elevated N reduced species richness by 16% at ambient CO_2 but by just 8% at elevated CO_2 .

The most likely scenario relevant for plant breeding is the following:

- Higher temperatures, which will reduce crop productivity, are certain
- Increase in CO_2 concentration is certain with both direct and indirect effects
- Increase in frequency of drought is highly probable
- Increase in the areas affected by salinity is highly probable
- Increase in frequency of biotic stress is also highly probable

Given this scenario, plant breeding may help by developing new cultivars with enhanced traits better suited to adapt to climate change conditions. These include drought and temperature stress resistance; resistance to pests and disease, salinity and water logging.

Breeding for drought resistance has historically been one of the most important and common objectives of several breeding programs on all the major food crops in most countries (Ceccarelli et al. 2007; Ceccarelli 2009a). Opportunities for new cultivars with increased drought tolerance include changes in phenology or enhanced responses to elevated CO_2. With respect to water, a number of studies have documented genetic modifications to major crop species (e.g., maize and soybeans) that increased their water-deficit tolerance (Drennen et al. 1993; Kishor et al. 1995; Pilon-Smits et al. 1995; Cheikh et al. 2000), although this may not extend to a wide range of crops. In general, too little is currently known about how the desired traits achieved by genetic modification perform in real farming and forestry applications (Sinclair and Purcell 2005).

Thermal tolerances of many organisms have been shown to be proportional to the magnitude of temperature variation they experience: lower thermal limits differ more among species than upper thermal limits (Addo-Bediako et al. 2000). Therefore a crop like barley, which has colonized a huge diversity of thermal climates may harbor enough genetic diversity to breed successfully for enhanced thermal tolerance.

Soil moisture reduction due to precipitation changes could affect natural systems in several ways. There are projections of significant extinctions in both plant and animals species. Over 5,000 plant species could be impacted by climate change, mainly due to the loss of suitable habitats. By 2050, the Fynbos Biome (Ericaceae-dominated ecosystem of South Africa, which is an International Union for the Conservation of Nature and Natural Resources (IUCN) 'hotspot' is projected to lose 51–61% of its extent due to decreased winter precipitation. The succulent Karoo Biome, which includes 2,800 plant species at increased risk of extinction, is projected to expand south-eastwards, and about 2% of the family Proteaceae is projected to become extinct. These plants are closely associated with birds that have specialized in feeding on them. Some mammal species, such as the zebra and nyala, which have been shown to be vulnerable to drought induced changes in food availability, are widely projected to suffer losses. In some wildlife management areas, such as the Kruger and Hwange National Parks, wildlife populations are already dependant on water supplies supplemented by borehole water (Bates et al. 2008).

With the gradual reduction in rainfall during the growing season, aridity in central and west Asia has increased in recent years, reducing the growth of grasslands and increasing the bareness of the ground surface (Bou-Zeid and El-Fadel 2002). Increasing bareness has led to increased reflection of solar radiation, such that more soil moisture evaporates and the ground becomes increasingly drier in a feedback process, thus adding to the acceleration of grassland degradation (Zhang et al. 2003). Recently it has been reported that the Yangtze river basin has become hotter and it is expected that the temperature will increase by up to 2°C by 2050 relative to 1950 (Ming 2009). This increase will reduce rice production by up to 41% by the end of the century and corn production by up to 50% by 2080.

The negative impact of climatic changes on agriculture and therefore on food production is aggravated by the greater uniformity that exists now particularly in the crops of developed countries agriculture compared to 150-200 years ago. The decline in agricultural biodiversity can be quantified as follows: while it is estimated that there are approximately 250,000 plant species, of which about 50,000 are edible, we actually use no more than 250; out of these 15 crops give 90% of the calories in the human diet, and 3 of them, namely wheat, rice and maize give 60%. In these three crops, modern plant breeding has been particularly successful, and the process towards genetic uniformity has been rapid – the most widely grown varieties of these three crops are closely related and genetically uniform (pure lines in wheat and rice and hybrids in maize). The major consequence of the dependence of modern agriculture on a handful of varieties for the major crops (Altieri 1995) is that our main sources of food are more genetically vulnerable than ever before, threatening the food. Already in early 20th century plant breeders warned that conventional plant breeding, by continuously crossing between elite germplasm lines, would drive out diverse cultivars and non-domesticated plants from the planet (Vavilov 1992; Flora 2001; Gepts 2006; Mendum and Glenna 2009). And climate change may exacerbate the crisis. Gepts (2006) claims that the current industrial agriculture system is "the single most important threat to biodiversity". The threat has become real with the rapid spreading of diseases such as wheat rust caused by newly emerged race UG99, but applies equally well to climatic changes as the predominant uniformity does not allow the crops to evolve and adapt to the new environmental conditions. The expected increase of biofuel monoculture production may lead to increased rates of biodiversity loss and genetic erosion. Another serious consequence of the loss of biodiversity has been the displacement of locally adapted varieties that my hold the secret of adaptation to the future climate (Ceccarelli and Grando 2000; Rodriguez et al. 2008; Abay and Bjørnstad 2009).

6. Combining participation and evolution: Participatory-Evolutionary Plant Breeding

One of the fundamental breeding strategies to cope with the challenges posed by climate change is to improve adaptation to a likely shorter crop season length by matching phenology to moisture availability. This should not pose major problems as photoperiod-temperature response is highly heritable. Other strategies include an increased access to a suite of varieties with different duration to escape or avoid predictable occurrences of stress at critical periods in crop life cycles, shifting temperature optima for crop growth, and renewed emphasis on population breeding.

In all cases the emphasis will be on identifying and using sources of genetic variation for tolerance/resistance to a higher level of abiotic stresses and the two most obvious sources of novel genetic variation are the gene banks and/or the farmers' fields. Currently there are several international projects aiming at the identification of genes associated with superior adaptation to higher temperatures and drought; at ICARDA, but also elsewhere, it has been found that landraces, and when available wild relatives harbor a large amount of genetic variation some of which would be of immediate use in breeding for drought and high temperature resistance (Ceccarelli et al. 1991; Grando et al. 2001).

The major difference between the two sources of genetic variation is that the first is static, in the sense that it represents the genetic variation available in the collection sites at the time the collection was made, while the second is dynamic, because landraces and wild relatives are heterogeneous populations and as such they evolve and can generate continuously novel genetic variation.

Adaptive capacity in its broadest sense includes both evolutionary changes and plastic ecological responses; in the climate change literature, it also refers to the capacity of humans to manage, adapt, and minimize impacts (Williams et al. 2008). All organisms are expected to have some intrinsic capacity to adapt to changing conditions; this may be via ecological (i.e., physiological and/or behavioral plasticity) or evolutionary adaptation (i.e., through natural selection acting on quantitative traits). There is now evidence in the scientific literature that evolutionary adaptation has occurred in a variety of species in response to climate change both in the long term as seen earlier in the case of stomata (Woodward 1987) or over relatively short time, e.g., five to 30 years (Bradshaw and Holzapfel 2006). However, this is unlikely to be the case for the majority of species and, additionally, the capacity for evolutionary adaptation is probably the most difficult trait to quantify across many species (Williams et al. 2008).
Recently Morran et al. (2009) have used experimental evolution to test the hypothesis that outcrossing populations are able to adapt more rapidly to environmental changes than self-fertilizing organisms as suggested by Stebbins

(1957), Maynard Smith (1978) and Crow (1992) explaining why the majority of plants and animals reproduce by outcrossing as opposed to selfing.

The advantage of outcrossing is to provide a more effective means of recombination and thereby generating the genetic variation necessary to adapt to a novel environment (Crow 1992). The experiment of Morran et al (2009) suggests that even outcrossing rates lower than 5%, therefore comparable with those observed in self pollinated crops such as barley, wheat and rice – outcrossing rates as high as 7% and 3.5% have been reported in barley (Marshall and Allard 1970; Allard et al. 1972) and in wheat (Lawrie et al. 2006), respectively – allowed adaptation to stress environments as indicated by a greater fitness accompanied by an increase in the outcrossing rates. This experiment, even though conducted on a nematode, is relevant for both self- and cross-pollinated crops and provides the justifications for evolutionary plant breeding, a breeding method introduced by Suneson more than 50 years ago working with barley (Suneson 1956), following the assumption of Harlan and Martini (1929) and of Allard (1960a) that with bulk breeding natural selection will, over time, evolve superior genotypes of self-pollinated plants. The "core features [of the evolutionary breeding method] are a broadly diversified germplasm, and a prolonged subjection of the mass of the progeny to competitive natural selection in the area of contemplated use". Its results showed that traits relating to reproductive capacity, such as higher seed yields, larger numbers of seeds/plant and greater spike weight, increase in populations due to natural selection over time.

The advantages of evolutionary participatory plant breeding have been reviewed recently by Murphy et al. (2005) using studies on yield, disease resistance and quality.

During periods of drought the yield of bulk populations increases over commercial cultivars selected under high input, but these yield advantages do not hold when conditions are agronomically favorable (Danquah and Barrett 2002); in dry bean Corte et al. (2002) found a mean yield gain of 2.5% per generation over the mean of the parents. This indicates that natural selection will favor high-yielding genotypes in environments with fluctuating biotic and abiotic selection pressures, a condition typical of most agro ecosystems. The positive effect of increasing genetic diversity on the control of persistent and flexible disease has been shown with the use of multilines (Garrett and Mundt 1999; Wolfe 1985; Zhu et al. 2000).

A genetically diverse bulk population allows for adaptation to disease through the establishment of a self-regulating plant–pathogen evolutionary system (Allard 1960b) an example of which has been documented in barley for the resistance to scald (caused by *Rynchosporium secalis*) where a reversal from an excess of susceptible families in the earlier generations to a greater percentage of resistance families after 45 generations was observed (Muona and Allard1982). In soybean F5 bulk populations grown on soybean cyst nematode infested soil the percentage of resistant plants increased from 5% to 40% while it remained at 5% when grown on uninfected soil (Hartwig et al. 1982).

Unlike yield and disease, quality is not directly influenced by natural selection and therefore, if quality is an important breeding objective, it is important to include high-quality parents in the crossing design.

At ICARDA, we are combining evolutionary plant breeding with participatory plant breeding (PPB), which is seen by several scientists as a way to overcome the limitations of conventional breeding by offering farmers the possibility to choose, in their own environment, varieties that suit better their needs and conditions. PPB exploits the potential gains of breeding for specific adaptation through decentralized selection, defined as selection in the target environment (Ceccarelli and Grando 2007).

The evolutionary breeding that ICARDA is combining with the participatory programs in barley and wheat, implemented in Syria, Jordan, Iran, Eritrea and Algeria, aims at increasing the probability of recombination within a population which is deliberately constituted to harbor a very large amount of genetic variation. In the case of barley such a population consists of a mixture of nearly 1600 F2 (Ceccarelli 2009b) while in the case of durum wheat the population consists of a mixture of slightly more than 700 crosses. The barley population has been planted in 19 locations in the 5 countries while the durum wheat population has been planted in 5 locations. Both populations will be left evolving under the pressure of the changing climatic conditions with the expectations that the frequency of genotypes with adaptation to the conditions (climate, soil, agronomic practices, biotic stresses) of the location where each year the population will increase. The simplest and cheapest way of implementing evolutionary breeding for the farmers is to plant and harvest possibly in the same location, but it is also possible to plant samples in other locations affected by different stresses or different combination of stresses by sharing the population with other farmers.

The breeder and the farmers can superimpose artificial selection with criteria that may change from location to location and with time. While the population is evolving, lines can be derived and tested as pure lines in the participatory breeding programs, or can be used as multilines, or a subsample of the population can be directly used for cultivation, exploiting the advantages of genetic diversity described earlier. The key aspect of the method is that, while the lines are continuously extracted, the population is left evolving for an indefinite amount of time thus becoming a unique source of continuously better adapted genetic material directly in the hands of the farmers. The latter guarantees that the improved material will be readily available to farmers without the bureaucratic and inefficient systems of variety release and formal seed production.

7. Conclusions

The major danger when discussing the adaptation of crops to climate changes is that these discussions usually take place in comfortable offices isolated both from the outside climate and from the people who will be most affected by its changes. By bringing back the analysis of the problems and the search for solutions to the thousands of smallholder/traditional family farming communities and indigenous peoples in the developing world who will be affected by climatic changes, by combining the indigenous agricultural knowledge systems with the scientific knowledge, and by making use of the lessons from the past we may be able to provide better adapted varieties that together with appropriate agronomic techniques can help millions of rural people to reduce their vulnerability to the impact of climate change.

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Genotype x environment interaction for durum wheat yield in Iran under different climatic conditions and water regimes

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Abstract

Climate change predictions indicate that the frequency of dry years will likely increase in the future. To cope with the climate change, wheat genotypes with adaptation to the changes are needed. An analysis of genotype by environment (G × E) interaction is necessary to develop such varieties. This study examined 20 durum wheat genotypes during the 2005-2007 cropping seasons over 19 diversified environments representing different ecosystems, water regimes, and climatic conditions. Pattern analysis and AMMI (additive main effects and multiplicative interaction) model were applied to grain yield data. The main effects due to environment, genotype and G×E interaction were highly significant. The results revealed several patterns of G×E interaction. Pattern analysis, classification and ordination analyses confirmed the cold and warm mega-environments, and allowed the discrimination and characterization of genotype adaptation. The environments belonging to the moderate locations tended to group with both cold and warm environmental groups, suggesting that the moderate locations will lead to the selection of genotypes that can be grown in cold and warm environments. Based on the AMMI model, the recommended genotypes had more grain yield improvement in favorable than unfavorable environments, and in the moderate than the cold and warm climatic conditions.

Keywords: climate changes, durum wheat, genotype x environment interaction, yield stability, pattern analysis.

Introduction

Genotype by environment (G × E) interaction has been of interest to plant breeders, geneticists, and production agronomists. Unrecognized G × E interaction can bias genetic-gain predictions and models for predicting growth dynamics or species perturbations by global climate change (Campbell 1992). To cope with the climate change, which is resulting in further insecurity of production, it is necessary to develop varieties that are adapted to a wide range of environments. Thus G × E interaction studies are important as the interaction plays a significant role in the expression of the performance of different cultivars in different environments.

The G × E interaction is commonly encountered when different genotypes (cultivars) are evaluated in multi-environment trials (MET) (Cooper and Hammer 1996; Kang 1998; Brancourt-Hulmel and Lecomte 2003; Yan and Kang 2003; Fan et al. 2007). The primary aim of MET in breeding programs is to estimate genotypic yields (Mohammadi and Amri 2009). The G x E interaction is commonly observed by crop producers and breeders as the differential ranking of cultivar yields among locations or years. The performance of genotypes evaluated in a broad range of environments is always affected by G x E interaction effect.

The climatic condition in Iran is very divergent and generally can be classified into five groups: very cold, cold, moderate cold, moderate warm, and very hot. The temperature varies from < -30 °C in the North West and central parts (Zanjan province) to > 50 °C in the South. Rainfall varies from < 100 mm in the Central Plateau to > 1000 mm in the North. In general, the climate in Iran is arid (annual average precipitation is almost 250 mm) and much of the relatively scant annual precipitation falls from October through April.

High population growth is driving up the demand for food in the world. Durum wheat is an important food crop for products such as Spaghetti, Macaroni, Pasta, and several traditional foods, for which there is large demand. World trade in durum wheat has increased considerably over the past few decades, rising to an average of 6.2 million tonnes annually during the 1990s-approximately 20% of world durum wheat production, compared to about 17% in the case of bread wheat-from an average of less than 2 million tonnes in the 1960s (ICARDA 2002). Durum wheat is grown on 10% of the world wheat area, mainly where rainfall is low (250-450 mm) and uncertain. Hence it is important for the food security of the dry areas.

The durum wheat breeding program in Iran is conducted in collaboration with the International Centre for Agricultural Research in the Dry Areas (ICARDA) and is aimed at developing varieties adapted to the different environments prevailing in Iran, including warm, cold, and mildly cold winter areas. The improved durum wheat genotypes are evaluated in multi-environment trials (MET) to test their performance across environments and to select the best genotypes in specific environments and also stable performing genotypes across a range of variable environments.

Materials and methods

Eighteen promising durum genotypes and two check cultivars (durum 'Zardak' and bread wheat 'Sardari') were evaluated at four different locations (provinces), representative of durum production areas in Iran, i.e. Kermanshah (34º19' N, 47º 07' E, and 1351 m AMSL) as moderate (M) location, Ilam (33º 41' N, 46º 35' E, and 975 m AMSL) as warm (W) location, and Maragheh (26º 52' N, 45º 30' E and 1400 m AMSL) and Shirvan (37º14' N, 58º 07' E and 1131 m AMSL) as cold (C) locations. The trials were conducted under rainfed and supplemental irrigation (50 mm irrigation in two stages: flowering and mid-anthesis) conditions over three cropping seasons (2005-07). The durum genotypes consisted of 18 promising lines, three from ICARDA and 15 from the durum wheat national breeding program. Information on environments and genotypes is given in Table 1. A randomized complete block design (RCBD) with three replications was used. Plot size was 7.2 m^2 (6 rows with 6 m length and 20 cm row-spacing). Fertilizer application was 50 kg N ha^{-1} and 50 kg P_2O_5 ha^{-1} at planting.

Combined analysis of variance (ANOVA) on grain yield data was performed to determine the effect of environment (E) [combining the effects of year (Y), location (L), and Y × L interaction], genotype (G), and all possible interactions among these factors. Yield data for 20 durum wheat genotypes and 19 testing environments were analyzed using the pattern analysis (Williams 1976) and AMMI (additive main effects and multiplicative interaction) model (Zobel et al. 1988; Gauch 1992) in IRRISTAT statistical software (IRRI 2005).

Results and discussion

Environment accounted for 85.5% of the total variation indicating the substantial effect of environment on the grain yield. Significant G x E interaction effects (14.4 %) demonstrated that the genotypes responded differently to variations in environmental conditions (Table 2). The large G x E effect relative to G (1.1%) suggests the possible existence of different mega-environments in durum wheat growing areas in Iran.

The mean grain-yield of genotypes across environments varied from 2271 kg/ha (for G3) to 2607 kg/ha (for G9) and the environment mean grain-yield across genotypes varied from 592 kg/ha in E12 (a rainfed environment at cold location) to 4167 kg/ha in E7 (an irrigated E at moderate temperature location). The mean grain-yield in the G x E data matrix ranged from 237 kg/ha at E12 (due to a severe drought) to 6975 kg/ha in E2 (under supplemental irrigation). Grain-yield data also indicated that genotypes failed to retain their relative yield ranking across the 19 environments. The G x E sum of squires (SS) was 12.2 times that of genotypes indicating the presence of sizable G x E interactions.

The results of ordination biplot analysis are presented in Fig. 1. The first two vectors in the biplot explained 52.3 % of total SS of the GE (Fig.1 and

Table 1. Information on testing environments and genotypes used in the study.

Environment						Genotype		
Code	Location	Crop-ping season	Status	Rainfall + irrigation (mm)	Climate	Code	Name	Origin
E1	Kermanshah	2004-05	Rainfed	431	Moderate	G1	44-16-2-4	Iran
E2	Kermanshah	2004-05	Irrigated	431+50	Moderate	G2	25-25-1-5	Iran
E6	Kermanshah	2005-06	Rainfed	515	Moderate	G3	40-11-2-3	Iran
E7	Kermanshah	2005-06	Irrigated	515+50	Moderate	G4	20-16-1-4	Iran
E13	Kermanshah	2006-07	Rainfed	552	Moderate	G5	18-18-1-4	Iran
E14	Kermanshah	2006-07	Irrigated	552+50	Moderate	G6	74-23-3-5	Iran
E4	Maragheh	2004-05	Rainfed	368	Cold	G7	73-16-3-5	Iran
E10	Maragheh	2005-06	Rainfed	382	Cold	G8	29-18-2-1	Iran
E11	Maragheh	2005-06	Irrigated	382+50	Cold	G9	71-7-3-5	Iran
E17	Maragheh	2006-07	Rainfed	418	Cold	G10	57-11-3-1	Iran
E18	Maragheh	2006-07	Irrigated	418+50	Cold	G11	43-25-2-4	Iran
E5	Shirvan	2004-05	Rainfed	242	Cold	G12	19-17-1-4	Iran
E12	Shirvan	2005-06	Rainfed	214	Cold	G13	409	Iran
E19	Shirvan	2006-07	Rainfed	284	Cold	G14	42	Iran
E3	Ilam	2004-05	Rainfed	552	Warm	G15	278	Iran
E8	Ilam	2005-06	Rainfed	574	Warm	G16	Gcn//Stj/Mrb3	ICARDA
E9	Ilam	2005-06	Irrigated	574+50	Warm	G17	Ch1/Brach// Mra-i	ICARDA
E15	Ilam	2006-07	Rainfed	470	Warm	G18	Lgt3/4/Bcr/3/ Ch1//Gta/Stk	ICARDA
E16	Ilam	2006-07	Irrigated	470+50	Warm	G19	Sardari (bread wheat check)	Iran
						G20	Zardak (durum check)	Iran

Table 2). The "which-won-where" view of the biplot (Yan et al. 2000) is an effective visual tool in mega-environment analysis. The vertices of the polygon are the genotype markers located farthest away from the biplot origin in various directions, such that all genotype markers are contained within the polygon. The vertex genotypes in this study were G19, G16, G17, G18, G3, G8 and G6 (Fig. 1). These genotypes were the best or the poorest genotypes in some or all of the sites because they had the longest distance from the origin of the biplot (Yan et al. 2007). The vertex genotype for each sector is the one that gave the highest yield for the environments that fell within that sector. Vertex genotypes without any environment in their sectors were not the highest performance genotypes in any environment, but were the poorest genotypes in most of the environments. The genotypes near to origin of biplot are more stable and tend to have wide adaptation.

In the 'relationship among testing environments', the cosine of the angle between the vectors (i.e., lines that connect the environments to the biplot origin) of two environments approximates the correlation between the two environments. The smaller the angle, the more highly correlated the environments (Yan and Kang 2003; Yan and Tinker 2006). As shown in Fig. 1, the environment vectors covered a wide range of Euclidean space indicating that the 19 environments represent a super-population of widely different environments, which agrees with the fact that they cover a wide range of climates of Iran. The maximum angle among the vectors of environments corresponding to cold and moderate locations was well below

Table 2. Analysis of variance for grain yield of 20 durum genotypes grown in 19 environments in Iran.

Source	DF	Sum of Squares	Mean Square	% explained variance
Environment (E)	18	274687008	15260389.3**	85.5%
Genotype (G)	19	3647685.25	191983.4**	1.1%
GE	342	42925440	125512.9**	13.4%
Total	379	321260128		
GE components [a]				
PCA 1	36	123.2	3.42**	34.1
PCA 2	34	65.7	1.93**	18.2
Residual	309	172.1	0.56	
Total	379	361		

[a] ANOVA for the PCA ordination of the transformed data
** Significant at 1% level of probability

90°, indicating that these environments tend to discriminate genotypes in similar manner, where the genotype G19 had the best adaptation to this group. Conversely the environments corresponding to warm locations were highly correlated and tended to make another environmental group with the genotypes G16 and G17 as winners. Two out of six environments corresponding to moderate location made the next environment group. These results show that the two locations, warm (Ilam location) and cold (Maragheh and Shirvan location), are different in genotype discrimination. The environments of the moderate location (Kermanshah) tended to group with both cold and warm environment groups, suggesting that the moderate location will lead to the selection of genotypes that can be grown in cold and warm environments. The difference in ranking of genotypes across environments indicated the presence of G x E interaction, which was confirmed by the significant effect of the G x E interaction (explaining 13.36 % of the treatment SS in the AMMI model). In Table 3, the first four AMMI recommended genotypes per environment (combination of year-climate location-water regime) are given. G19 was in the top four ranks in 10 of 19 environments and was

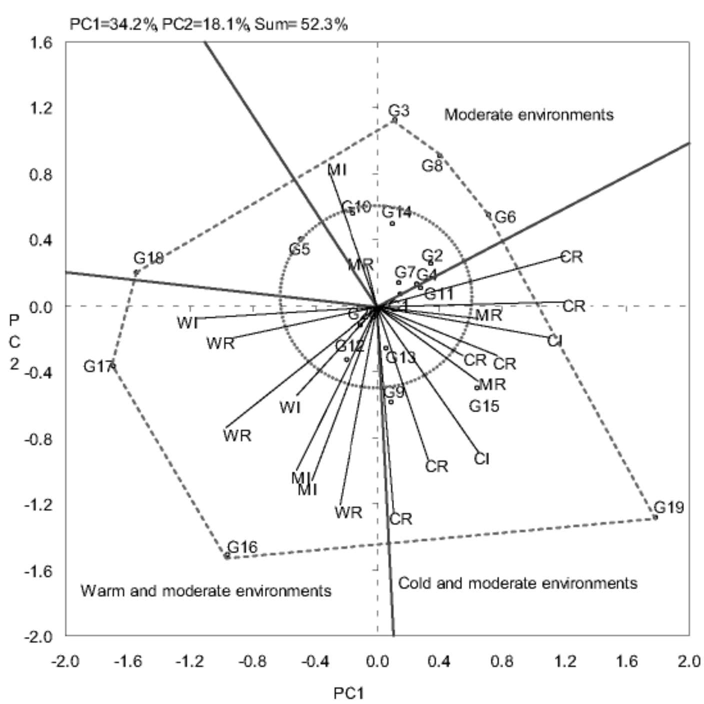

Figure 1. Biplot analysis of PC1 vs. PC2 for grain yield on 20 genotypes grown in 19 environments. Environments are characterized by vectors drawn from the biplot origin and entries are the genotypes. W, C and M stand for warm, cold and moderate environments, respectively. R and I stand for rainfed and irrigated conditions, respectively.

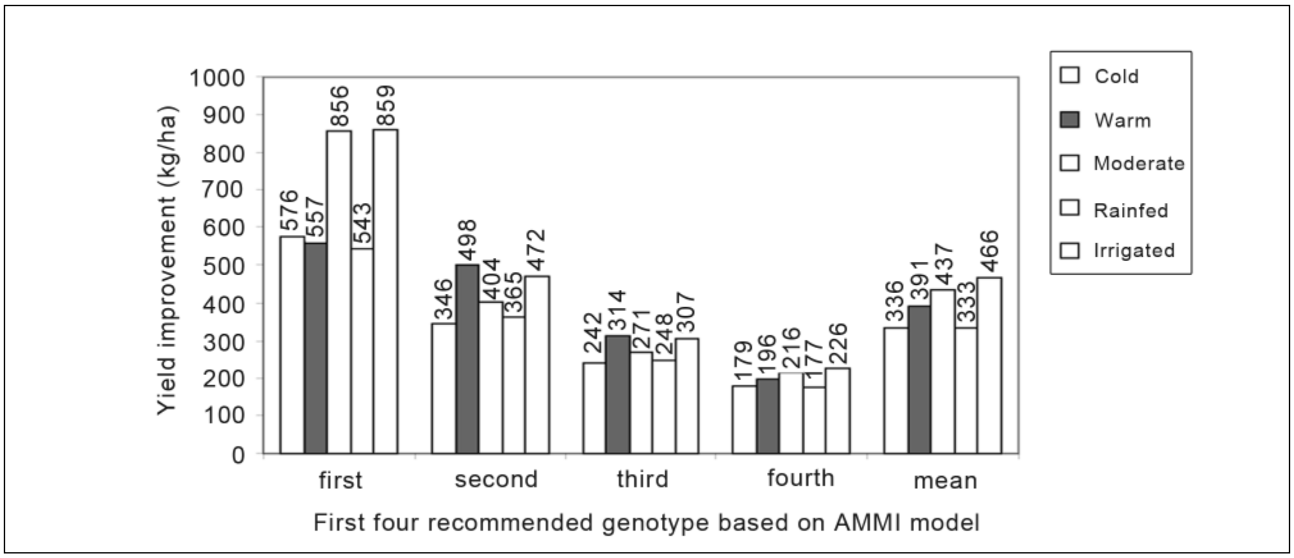

Figure 2. The expected yield improvement using the first four AMMI recommended genotypes under different climate and water-regime conditions of Iran.

the dominant genotype in eight environments. G16 was in the top four ranks in 9 out of 19 environments and was identified as dominant genotype in three environments; G18 was the dominate genotype in three environments and appeared in the top four ranks in six of 19 environments; G17 was the dominant genotype in four environments and ranked in the top four ranks in five environments, while G9 was dominant in one environment and appeared in 10 environments within the top four ranks. The other superior genotypes that were not classified as dominant, but appeared consistently 10, 8, 6, 3, 2, 2, 2, 1 and 1 times in the top four ranks across 19 environments were G15, G12, G1, G13, G5, G6, G4, G7 and G11, respectively. Table 3 also illustrates the importance of recommending the right genotype for each environment. In this case, a yield improvement of 659 kg/ha could be achieved across 19 environments if only the dominant genotype for each environment is planted. If the second, third and fourth recommended genotypes are planted across 19 environments the yield improvements of 404, 270 and 195 kg/ha could be achieved, respectively. If the dominate genotypes were also planted separately for each rain-fed and irrigated environment, yield improvements would be equal to 543 and 859 kg/ha, respectively, indicating that the top genotypes had more yield improvement under favorable environments.

The suitable locations for the first four top genotypes were identified. The promising genotypes G15, G9 and G12 were highly adapted to moderate location under rain-fed condition in three years and had consistent responses as three top genotypes. For this location, some fluctuations regarding the responses of genotypes under irrigated conditions were observed, however the genotypes G9 and G12 in two out of three years ranked as top genotypes (Table 3). In warm location (Ilam), all the three promising lines from ICARDA (G17, G18 and G16) were the top ones for three years in the both rain-fed and irrigated conditions. In cold location (Maragheh), the genotypes G15 and G1 for rain-fed conditions and G15 and G16 for irrigated conditions had the best responses. The best adapted top genotypes for another cold location (Shirvan) were G15, G9 and G1. However in most of the locations, except Ilam, bread wheat check cultivar Sardari (G19) appeared as most widely adapted cultivar.

Fig. 2 shows the importance of recommending the right genotype for each climate and water regime conditions over three years. The highest yield improvement will be achieved at moderate location (866 kg/ha) followed by cold and warm locations, if the dominant genotypes are planted there. If the dominant genotypes were planted in locations under the rainfed and irrigated conditions, yield improvements equal to 859 and 543 kg/ha respectively could be achieved over three years (Fig. 2). Based on the AMMI model, the recommended genotypes had more grain yield improvement: (i) in favorable (irrigated) than unfavorable (rainfed) environments and (ii) in the moderate than the cold and warm climate conditions.

Iran is currently one of the world's largest net importers of agricultural products, importing about 30% of its requirements. Rapid population growth is expected to increase the demand for food. The extension of planted area with improved durum wheat cultivars can contribute to food security in Iran. However, the major challenges of durum wheat breeding are the need for identification of genotypes with good cold tolerance and to distil out useful information within the available data.

Both pattern and AMMI analyses allowed a sensible and useful summarization of G x E data set and assisted in examining the natural relationships and variations in genotype performance among various environmental groups. It also assisted refining the breeding strategy for durum wheat in Iran with the identification of two contrasting warm and cold mega-environments.

As the G x E interaction is important in determining performance and adaptation, so, evaluation based on several years and locations is a necessary strategy to be pursued in breeding programs. Farmers in developing countries, using no or limited inputs or growing crops under harsh and unpredictable environments, need varieties with yield stability (Mohammadi and Amri 2008). In these cases, genotypes with good performances and stability should be recommended. For this reason, G x E interaction analysis can help to characterize the response of genotypes to changing environments and to determine the best locations representative of the environmental diversity in major growing areas of any crop.

Table 3. Environments grouping using the dominant yielding genotypes and the expected yield improvement using the first four AMMI recommended genotypes.

Environment		First four AMMI genotypes recommended per environment								Yield improvement (kg/ha)			
Climate -water regimea	Mean	1stb	yield	2nd	yield	3rd	yield	4th	yield	1st	2nd	3th	4th
C-IR	2244	G19	3257	G15	2767	G6	2666	G9	2520	1013	523	422	276
C-RF	2241	G19	3060	G15	2701	G6	2513	G11	2442	819	460	272	201
C-RF	1593	G19	2384	G15	2052	G4	1827	G1	1819	791	459	234	226
C-IR	2476	G19	2990	G15	2767	G16	2693	G13	2636	514	291	217	160
C-RF	1313	G19	1654	G15	1559	G9	1469	G1	1404	341	246	156	91
M-RF	2970	G19	3316	G15	3204	G9	3167	G12	3074	346	234	197	104
C-RF	1101	G19	1404	G15	1329	G9	1254	G1	1190	303	228	153	89
M-RF	3225	G19	3467	G15	3421	G9	3380	G12	3307	242	196	155	82
W-IR	2815	G19	3342	G1	3251	G7	3116	G16	3023	527	436	301	208
W-IR	3090	G17	3865	G18	3767	G16	3408	G12	3238	775	677	318	148
W-RF	2462	G17	3246	G18	3178	G16	2871	G12	2666	784	716	409	204
W-RF	2599	G17	3009	G18	2975	G16	2876	G12	2768	410	376	277	169
M-IR	3021	G18	4116	G5	3319	G4	3298	G1	3211	1095	298	277	190
M-IR	4167	G18	4567	G17	4395	G12	4376	G9	4370	400	228	209	203
M-RF	2317	G18	3682	G5	2934	G12	2699	G9	2632	1365	617	382	315
M-IR	3687	G16	5373	G13	4539	G9	4095	G12	4087	1686	852	408	400
C-RF	2282	G16	2951	G19	2701	G1	2623	G15	2538	669	419	341	256
W-RF	2198	G16	2488	G9	2485	G13	1462	G12	2450	290	287	264	252
CRF	592	G9	751	G19	732	G15	731	G16	723	159	140	139	131
Mean	2442		3101		2846		2659		2637	659	404	270	195

[a] W, C and M stand for warm, cold and moderate environments, respectively. R and I stand for rainfed and irrigated conditions, respectively; [b] Dominant genotype

In the highlands of Iran, there is a need to develop better-adapted and higher-yielding durum cultivars to compete with bread wheat and increase the area devoted to durum wheat. Cultivars have mostly been selected in Iran, like in other developing countries, in favorable environments and then introduced with technological packages (e.g., mineral fertilizer, pesticides, irrigation) designed to significantly improve the growing environment (Simmonds 1979). Fortunately, the results of less than 12 years of joint breeding efforts of ICARDA and the Dryland Agricultural Research Institute (DARI), Iran, have led to the release of stable durum genotypes with high-yielding ability in low inputs conditions.

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Thermo-tolerance studies on barley (*Hordeum vulgare* L.) varieties from arid and temperate regions

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Abstract

Plants growing in arid regions can suffer from high shoot temperatures, low shoot water concentrations, low turgor pressures, and high salinity in the rhizosphere. In this study a series of experiments was undertaken to establish the importance of short periods of high leaf temperatures (T_{leaf}) on photosynthesis rates as this will affect a plant's ability to tolerate and survive other stress factors. Three barley lines were used, 'Optic' (an elite European cultivar), 'Soorab-96' (an elite cultivar developed by ICARDA and grown extensively in Pakistan), and 'Local' (an uncharacterized landrace grown in Western Pakistan). In all three lines light saturated carbon dioxide assimilation rates (A_{sat}) and the carboxylation coefficients (ΦCO_2), determined from A/Ca and A/Ci curves, respectively, in the fourth fully expanded leaves were equally suppressed to ~20% of their pre-treatment levels immediately after a short period of heat stress (T_{leaf} > 40.0° ± 0.5°C for 20 minutes).

Five days after heat stress A_{sat} and ΦCO_2 had recovered to ~40% of their pre-stress levels in line Local ($p<0.05$), but no significant recovery was observed in Soorab-96 or Optic. Parallel measurements using a range of techniques confirmed the suppression of A_{sat} and ΦCO_2 was not attributable to changes in the light harvesting capacity (leaf absorptance and chlorophyll a excitation spectra), maximum quantum efficiency of PSII (ΦPSII, Fv/Fm), or to stomatal conductance (g_s). It is unlikely that the suppression arose from damage to the electron transport chain¸ or to the capacity to develop or maintain non-photochemical quenching (NPQ, which is dependent on the transthylakoid ΦpH), but these possibilities cannot be dismissed. Taken together these data suggest when barley leaf temperatures exceed 40°C for as little as twenty minutes the activity of the C_3 cycle is severely impaired resulting in a major decline in leaf photosynthesis rates. It is not yet clear whether this suppression in activity is due to the direct effects of high leaf temperatures on the kinetic properties of enzymes involved in the C_3 cycle or to changes in the mesophyll conductance to CO_2 (g_m). Some landraces have the potential to repair and partly recover from this thermal damage and thereby survive, but this ability is not retained in the elite barley cultivars investigated in this study.

Keyword: barley, heat stress, photosynthesis, thermal stress.

Abbreviations: A, CO_2 Assimilation Rate: A_{sat}, light saturated CO_2 Assimilation Rate: Ca and Ci, external and internal leaf CO_2 concentration, respectively: Chla and Chlb, chlorophyll a and b: E, transpiration rate: ETR, photosynthetic electron transport rate determined from fluorescence measurements: Φ_{PSII}, maximum quantum efficiency of PSII (Fv/Fm): ΦCO_2, Carboxylation Efficiency, the initial slope of A/Ci plots: g_s, stomatal conductance: IRGA, Infra Red Gas Analyser: NPQ, non-Photochemical Quenching: T_{leaf} and T_{air}, leaf and air temperature, respectively.

1. Introduction

To meet the rising global demand for food it will be necessary to both increase yields on land currently cultivated, and to appropriate new land for arable production. For the long term protection of the environment new production will have to be achieved on marginal lands that hitherto has been considered too uneconomical for the production of the major cereals (Fischer et al. 2005).

Large tracts of marginal land are available at high latitudes in the Americas and Asia; here spring rainfall and temperatures are adequate, but sporadic early spring frosts prove catastrophic for the production of maize and wheat (Porter 2005). In addition, at lower latitudes there are extensive tracts of arid land (e.g. in the Americas, Asia, Africa, and Australia) but here cereal production is limited by a range of abiotic stress factors and plants are faced with a number of different challenges (Lobell and Asner 2003). Extractable soil water content may be low, and the water potential of what is available may also be low (more negative than -1.3 MPa) due to the presence of high levels of electrolytes. For crops to grow well in these regions several complex traits are required including the uptake and compartmentation or exclusion of electrolyte, and the extraction of moisture from soils with low field capacities.

In addition to these rhizosphere stresses, high vapour pressure deficits (VPDs) are normal in these regions leading to excessive water loss through transpiration resulting in an initial loss of turgor pressure, and in very extreme cases of desiccation to low tissue water concentrations that impair metabolism. Loss of turgor has several important consequences for plant growth and survival such as reductions in cell expansion (growth) and stomatal conductance (g_s) which will in turn prevent carbon dioxide assimilation and evaporative cooling of leaves (Cornic 2000; Lu and Huang 2008; Radin et al. 1994) and the transport to the shoot of nutrient ions via the transpiration stream. Again, a large number of genes will be required to encode the proteins that carry out these various processes. These include those associated with the following: g_s (signalling, density, morphology, etc.,); heat tolerance (heat shock proteins, dissipation of absorbed light energy); and the acquisition, synthesis and compartmentation of inorganic and compatible organic solutes for regaining turgor pressure (Wahid et al. 2007). What is clear is that the prospect of a single plant from an elite line containing all of the best alleles at the corresponding loci is very remote although some of the poorly characterized landraces of these crops may provide germplasm that contains some of the desired characters, and this has hampered the development of ideal lines using conventional breeding techniques. For similar reasons, the development of suitable crop lines through single-gene genetic manipulation approaches has been slow as often there has not been a sufficient depth of understanding of the different stresses encountered by plants growing in arid zones. A strong case can be made for the collection of germplasm for the major cereals and to attempt to identify desirable alleles that confer tolerance to single stress factors in controlled experiments rather than to assess germplasm in field trials for all of the desired traits together (e.g. high soil salinity, high leaf temperatures, low soil water content, low tissue water potentials, etc.).

The loss of relatively small amounts of tissue water (~15%) results in the collapse of turgor and consequently the impairment of growth, carbon assimilation, nutrient ion movement in the transpiration stream, and the capacity to cool leaves. Whilst suppression of each of these processes will compromise crop growth and yields in the long term, it seems likely that high leaf temperatures may cause severe damage in the short term which, could compromise a plant's ability to tolerate and recover from other stress factors (Schöffl 1999).

In this study we report the results for a series of experiments to assess the effects of high leaf temperatures (T_{leaf}) on photosynthesis and stomatal conductance (g_s) in three barley lines. 'Soorab-96' is an elite ICARDA line developed for and grown extensively in Central and Eastern Pakistan (Rashid et al. 2006). 'Local' is one of many poorly characterized landraces grown in the arid parts of Western Pakistan chiefly for animal fodder (Khan et al. 1999). 'Optic' is an elite European line grown extensively in Northern UK for malting purposes. The results of this study show inherent differences between these lines with respect to their ability to survive and recover from thermal stress.

2. Material and methods

2.1. Plant material

Seeds of three barley lines (Local, Soorab-96, and Optic) were germinated in tap water and after 5 days transplanted into 2 L pots containing a 1/1 volume mixture of Perlite and Levington's compost and placed in a controlled environment growth room (14/10 hour Day/ Night photoperiod, light intensity 200 µmoles.m^{-2}.s^{-1}, 22/18 ºC temperature, humidity 60%).

2.2. Exposure to heat stress

Two experiments were conducted. In the 'Short Term' experiments CO_2 assimilation and transpiration rates were measured from an attached leaf whilst T_{air} was increased concomitantly. In the 'Long Term' experiments CO_2 assimilation rates, transpiration, and chlorophyll fluorescence measurements were made before and after an attached leaf was held at a single T_{leaf} for three hours. In both experiments fully expanded 4th emergent leaves were used (approximately one-month from sowing).

'Short Term' experiments: An attached leaf was sealed in the narrow leaf chamber of an *LCPro*+ Infra Red Gas Analyzers (IRGAs, ADC Bioscientific, Herts, UK) using the following conditions: irradiance 550 μ mol m^{-2} s^{-1} white light generated from Philips HPLR 400W Mercury Vapour lamps; gas flow rate 200 μ mol s^{-1} , Ca (CO_2 concentration in air) 38 Pa, water vapour 0 Pa. T_{air} was increased incrementally from 25°C to 44°C (±0.5°C) and steady state light saturated rates of Assimilation (A_{sat}) and transpiration were measured for at least 10 minutes (i.e. ~20 minutes at each temperature).

'Long Term' experiments: A suitable piece of attached leaf (~80 mm from the base of the leaf) was identified, marked and placed in a narrow leaf chamber of the IRGAs (set at T_{air} 25°C ±0.5°C) and CO_2 response curves determined (A/Ca and A/Ci) along with the corresponding transpiration rates (Farquhar and Sharkey 1982; Farquhar et al. 1980). In addition, various chlorophyll fluorescence measurements were made using a WALZ MINI-PAM fluorimeter fitted with a 2030-B Leaf Clip and an external actinic light (550 μ mol m^{-2} s^{-1} delivered by a 50W quartz halogen bulb); these measurements included the maximum quantum yield of photosystem II photochemistry (Fv/Fm of dark adapted leaves, Φ_{PSII}), maximum and steady state rates of photosynthetic electron transport (ETR), and non-photochemical quenching (NPQ) during light induction and dark recovery (Baker 2008).

2.3. Measurement of leaf absorptance and light harvesting capacity

Leaf absorptance was measured before and after heat stress using a Perkin Elmer λ800 spectrophotometer fitted with a Labsphere PELA-1020 Integrated Sphere (2 nm slit widths). The efficiency of light absorption and exciton delivery to PSII reaction centres was assessed from Chla excitation spectra measured at room temperature using a Perkin Elmer LS55 fluorimeter fitted with a fibre optic attachment (excitation 350-600 nm with 5 nm slit widths; emission, 680 nm 10 nm slit widths). Thirty minutes before measurement, leaves were pre-treated with 50 μ M DCMU (3-(3,4-dichlorophenyl)-1,1-dimethylurea) to block photosynthetic electron transport and attain the maximal level of fluorescence (Fm).

2.4. Statistical analysis

Statistical analysis was performed using the General Linear Model ANOVA routine in MINITAB (ver. 15) with barley line as a fixed factor (3 levels) and time from heat stress (3 levels) as a random factor. Where appropriate, differences between treatments were assessed using Tukey's pair wise comparison tests.

3. Results

To assess the effects of brief periods of high temperature stress on the photosynthetic competence of barley leaves, fully expanded 4th emergent leaves were sealed in the leaf chamber of an IRGA and steady state Asat and transpiration (E) rates recorded over a range of incrementing T_{air} starting at 25ºC and finishing at 44ºC (± 0.5ºC). Steady state reading of Asat and E were recorded once constant readings were obtained for at least 10 minutes (typically this required T_{air} to be held constant for approximately 20 minutes) and T_{leaf} was monitored during this period. Figure 1 presents the data from these experiments for the three barley lines.

The response of the three lines to short-term increases in T_{leaf} was similar. Increasing T_{leaf} from 23ºC to ~40ºC produced only a minor decrease in Asat, but beyond this range the values declined rapidly to 25-35% of their initial values ($p<0.05$; Fig 1a). There is some evidence that Asat in the European line Optic is more sensitive to increasing T_{leaf} than the Pakistani lines Soorab-96 and Local, but this may result from the inherently higher rates measured in this line.

Transpiration rates (E) increased significantly with T_{leaf} particularly at temperatures in excess of 36ºC and the rates were always significantly higher in Optic than in the other two lines (Fig. 1b). The observed increase in E arises partly from an increase in the VPD that accompanied the increase in T_{leaf} and T_{air}, but Figure 1c also shows that above

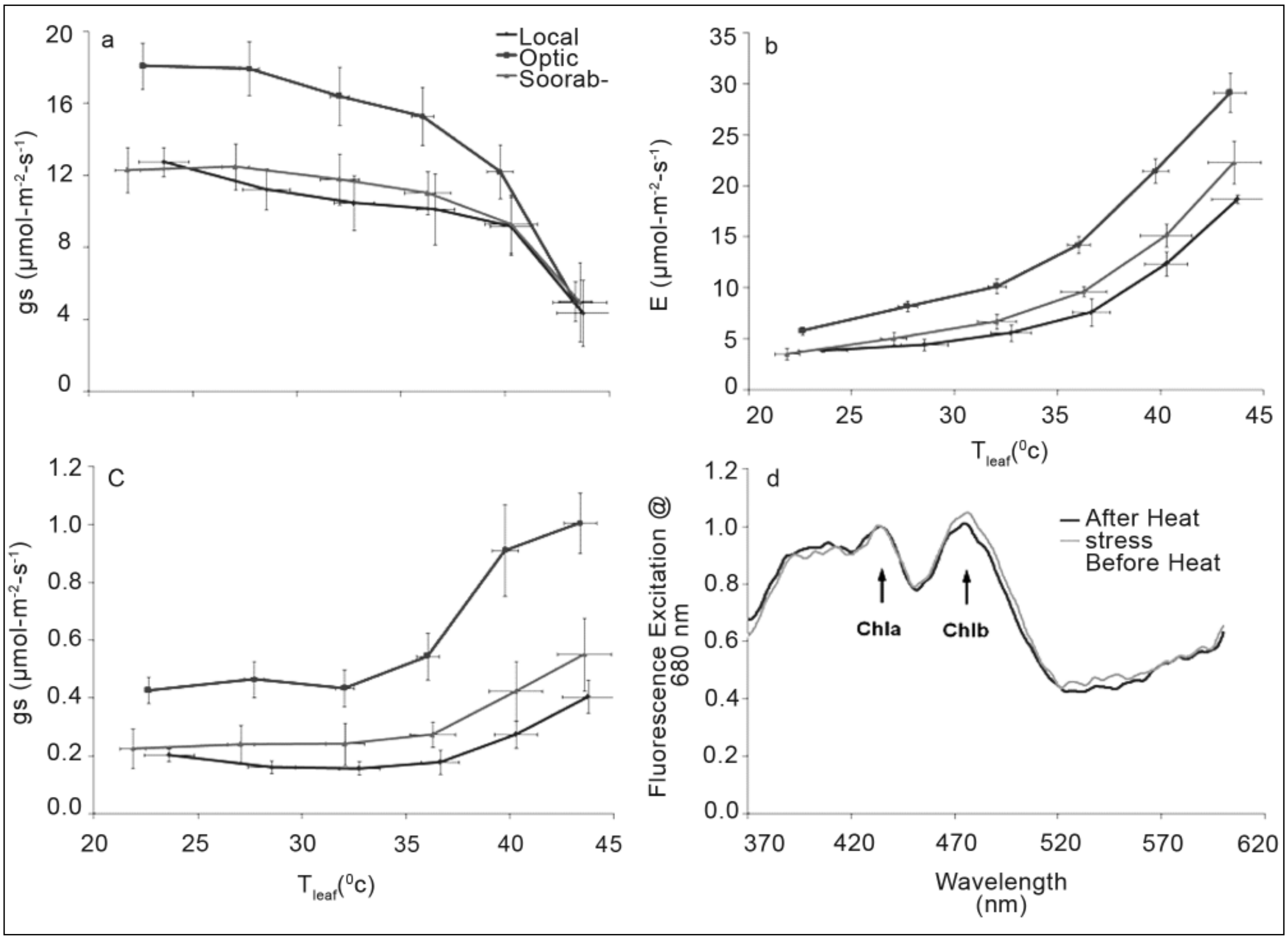

Figure 1. Profile of increasing leaf temperature on photosynthesis and transpiration rates in single leaves of three barley lines. Attached fully emerged 4th leaves of the barley lines Optic, Local, and Soorab-96 were sealed in leaf chambers and exposed to ambient air at 25ºC and saturating light (550 µ mol m^{-2} s^{-1} PAR) until steady state rates of light saturated CO_2 Assimilation (A_{sat}), transpiration (E), and leaf Temperature (T_{leaf}) were achieved (for full details see Materials & Methods). Once steady state readings were attained for ~10 minutes, an increase in T_{air} was programmed and the new steady state values recorded. The values represent the average and standard errors of 5 independent leaves for each line. a, A_{sat} *versus* T_{leaf}: b, transpiration rate (E) versus T_{leaf}: **c,** Stomatal Conductance (g_s) versus $T_{leaf.}$: **d,** a typical Chla fluorescence excitation spectra from a single Optic leaf before and after T_{leaf} was held at 40.0ºC (± 0.2ºC) for three hours (see Materials & Methods for full details).

~36ºC all of the lines significantly increased stomatal conductance (g_s; $p<0.05$). Taken together these data indicate the observed decline in Asat induced by brief increases in T_{leaf} were not attributable to stomatal limitations on CO_2 uptake.

Measurements on the light harvesting capacity of the photosynthetic apparatus before (T_{leaf} 23ºC) and after a twenty minute heat stress period (T_{leaf} 44ºC) indicate no major changes in leaf absorptance measured using an integrating sphere (data not presented). The efficiency of light capture and exciton energy transfer from the Chl*b*-containing peripheral light harvesting complexes (LHCs) to the Chl*a* containing PSII core units can be assessed from room temperature excitation spectra. Here fluorescence emission (at 680 nm) emanates from Chl*a* in the core PSII unit which are excited directly through Chl*a* absorbtion (from 420-445 nm), or through Chl*b* absorbtion in the peripheral LHCs (from 460-490 nm) and energy transfer to Chl*a* in the PSII core. The ratio of the fluorescence emission excited directly through Chl*a* and Chl*b* therefore provides an estimate of the efficiency of light absorbtion and energy transfer from the peripheral Chl*a*/Chl*b*-containing LHCs to the Chl*a*-containing PSII units. These spectra indicate that excitation of PSII core complexes through Chl*a* and Chl*b* is similar before and after heat stress implying the observed decline in Asat is not attributable to a decrease in the rate of energization of the PSII reaction centres (Fig. 1d).

Figure 2 presents a cartoon of the processes that could effect short term changes in Asat. For convenience, four processes are considered: 1) Light Harvesting Capacity (the absorption of light and delivery to the reaction centres of PSI and PSII, RCI and RCII respectively); 2) the production of NADPH and ATP in the stroma for CO_2 assimilation (photochemistry, photosynthetic electron transport, chemiosmosis, etc.); 3) the kinetic properties of the enzymes of the C_3 cycle (Km, Vmax, etc.); 4) the supply of CO_2 to the chloroplast stroma (controlled mainly by g_s, and mesophyll conductance, g_m). The data presented in Figure 1 suggest that rapid changes in the light harvesting capacity and g_s are not responsible for the observed changes in A_{sat} and that these are most likely attributable to the processes encapsulated in stages 2 and 3 of Fig. 2.

The effects of brief increases in T_{leaf} on PSII photochemistry and whole chain photosynthetic electron transport rates (ETRs) was assessed using saturating light pulses and modulated fluorescence techniques. Figure 3 presents the results from A/Ca and Chl*a* fluorescence measurements on fully expanded 4th emergent leaves of the three

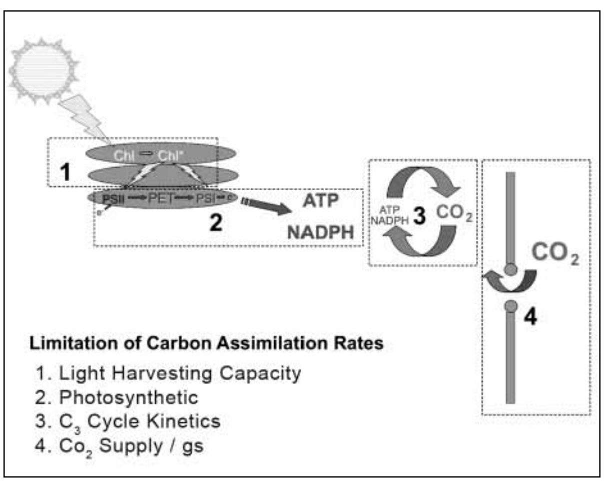

Figure 2. Schematic diagram of the processes affecting leaf CO_2 assimilation rates. Assimilation rates can be affected changes in the efficiency of one or more processes that contribute to leaf photosynthesis. **1**, light capture and exciton transfer to PSI and PSII reaction centres (RCI and RCII): **2**, Photochemistry in RCI and RCII, photosynthetic electron transport rates (ETR), the generation of ATP (by chemiosmosis) and NADPH (via electron transfer from ferridoxin-NADP+ reductase): **3**, the kinetic properties of the enzymes of the C_3 cycle**: 4**, the combined conductances controlling the delivery of CO_2 from air to the chloroplast stroma (boundary layer, stomatal, and mesophyll conductances).

barley lines. In these experiments measurements were made on the same piece of attached leaf immediately before, immediately after, and five days after raising T_{leaf} to 40.0 ±0.2ºC for 3 hours using a modified thermal cycler (Long Term Heat Stress experiments, see Material & Methods).

From the A/Ca (CO_2 assimilation versus external CO_2 concentration) curves, A/Ci (assimilation *versus* internal CO_2 concentration) plots were constructed and the initial linear slopes of these used to estimate the carboxylation efficiency (V_{cmax}), a measure of the overall activity of the C3 cycle. With all three lines raising T_{leaf} to 40.0 ±0.2ºC for 3 hours severely impaired A_{sat} to less than 15% of their initial rates (data not presented), and a similar decline was observed in V_{cmax} (Fig. 3a); this suppression could not be attributed to stomatal function (Fig 3.f). Increasing T_{leaf} also severely impaired steady state ETR and maximal ETR (measured using fluorescence techniques) in Optic and Local to ~20-30% of their pre-stressed values (Fig. 3c & 3d). In contrast, raising T_{leaf} produced significant ($p<0.05$) but relatively modest suppression of the maximum quantum efficiency of PSII (ΦPSII; i.e. Fv/Fm of fully dark adapted leaves) and the Non-Photochemical Quenching parameter (50-60% of the pre-stressed values; Fig. 3b &3e, respectively). No major differences between the three lines were observed in the initial responses of leaves to heat stress.

Figure 4 presents images of leaves from the three lines before and 5 days after heat stress (T_{leaf} to 40.0 ±0.2ºC for 3 hours). In all replicates Optic showed the greatest level of heat stress damage and Local the least implying leaves of line Local have the capacity to partially recover from thermal damage. To investigate this observation further, measurements of A/Ca responses and fluorescence parameters were monitored on the same piece of attached leaf for up to 5 days post heat stress to assess recovery of photosynthetic competence; these data are also presented in Fig 3. Measurement of ΦCO_2 (from A/Ci curves) showed leaves from line Local significantly recovered part of their lost capacity 5 days after stress ($p<0.05$; Fig. 3a); no significant recovery was observed in Soorab-96 or Optic. The values of Φ_{PSII}, and the rates of steady state ETR and maximal ETR also suggested some recovery may have occurred in line Local but these were not significant (Fig. 3b-3d).

4. Discussion

The experiments reported here indicate brief elevation of leaf temperature to 40°C for just a few minutes severely impairs CO_2 assimilation in barley leaves. Leaf temperatures of this magnitude are not uncommon for water limited plants growing in habitats of high irradiance (Bucks 1984; Drake 1976; Mattson and Haack 1987). Whilst high leaf temperatures suppressed several processes that contribute to CO_2 assimilation, for example $\Phi_{PSII.}$ and ETR, it appears that the processes most closely associated with the C_3 cycle are affected the most. These include the kinetic properties of the individual enzymes involved in the C_3 cycle itself (Km, Vmax, etc.), as well as the supply of substrates to drive CO_2 assimilation (CO_2, ATP, and NADPH). Whilst there was no evidence that g_s was suppressed by high leaf temperatures, it is conceivable that CO_2 concentration in the stroma was low due to thermally-induced decreases in mesophyll conductance (g_m) or perturbations

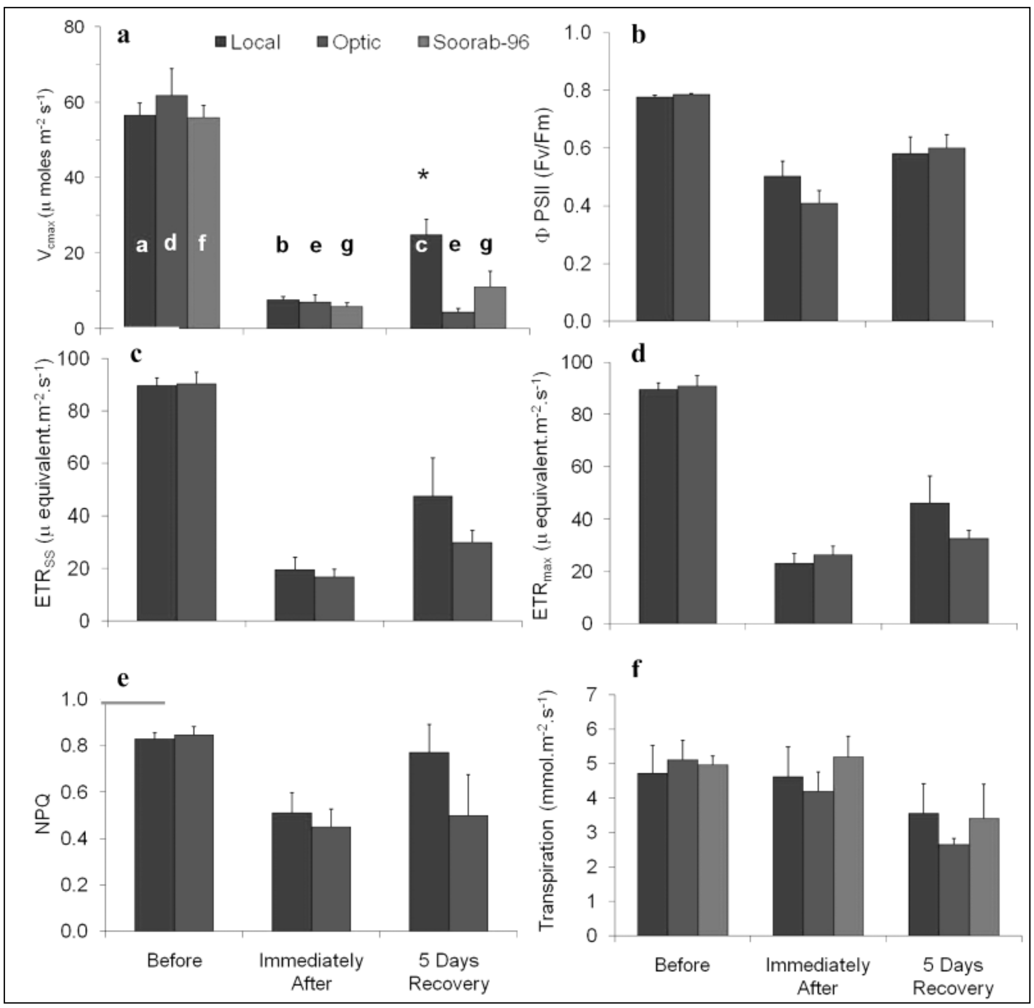

Figure 3. The effects of three hours heat stress on barley leaf function. A variety of photosynthetic parameters were measured at Tleaf 23ºC (± 0.5ºC) and saturating light levels (550 µ mol m^{-2} s^{-1} PAR) immediately before, immediately after, and then every day after subjecting a marked region of an attached barley leaf to heat stress. Fully expanded 4th emergent leaves were used from the lines Optic, Local, and Soorab-96 ~80 mm from the base of the leaf blade. Heat stress was imposed by increasing Tleaf to 40.0ºC (± 0.2ºC) for three hours using a modified thermal cycler (see Materials & Methods). The presented values are the averages and standard errors of 4 or 5 replicates. Data for plots a and f were collected using IRGAs, and for plots b-e using pulse modulated fluorescence techniques (see Materials & Methods). Different capital Roman letters indicate significant differences between treatments (within Line) at $p<0.05$ (pooled Standard Errors). a, the Carboxylation Efficiency (Φ CO_2) derived from the initial slope of A/Ci curves determined with IRGAs. b, the maximum Quantum Efficiency of PSII Photochemistry (ΦPSII; i.e. Fv/Fm of fully dark adapted leaves). c, steady state Electron Transport Rates (ETR) determined after ~10 minutes irradiation. d, maximum ETR determined during the light induction part of the fluorescence measurements. e, the Non-Photochemical Quenching (NPQ) component measured at steady state. f, transpiration rates (E) measured when Asat was at steady state.

of the equilibrium set by carbonic anhydrase in mesophyll cells (Bernacchi et al. 2002). Neither of these possibilities was checked in this study and this, along with measurements on the kinetic properties of the constituent enzymes of the C_3 cycle, now requires further investigation.

What is clear is that the suppression of CO_2 assimilation induced by brief elevation of T_{leaf} to 40°C does not arise from changes in the excitation rate of photochemical efficiency of PSII. This precludes the involvement of protective mechanisms that are reported to regulate the fate of absorbed light energy such as the Xanthophyll cycle, state transitions, or photoinhibition (Baker 2008). The activation of such mechanisms would have been reflected in the various fluorescence parameters determined from induction and dark recovery (not presented) experiments carried out in this study. Although high leaf temperatures did affect some of these fluorescence parameters, they were relatively minor compared with the suppression observed in CO_2 assimilation. Of particular interest is the modest effect of elevated leaf temperatures on ΦPSII It is well established that the D1 protein that constitutes part of the hererodimeric core of the PSII reaction centre is prone to damage (Allakhverdiev et al. 2008). Some evidence was found to support the contention that primary photochemical processes were affected but these may have arisen because the major electron sink (CO_2 assimilation) was suppressed and not as a direct cause of thermal stress *per se*. The data presented here are consistent with reports of an indirect thermally-induced decrease in the activity of Ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCo) due to inactivation of RuBisCo activase (Kurek et al. 2007; Salvucci and Crafts-Brandner 2004; Salvucci et al. 2001).

One of the interesting observations from the short-term heat stress experiments (Fig.1) is the rapid response of stomata to increasing leaf temperature. As T_{leaf} was increased from 23°C to 36°C (T_{air} from 25ºC to 40ºC) the driving force for transpiration, the VPD more than doubled (from 2.80 to 5.92 KPa) but g_s remained unchanged. In contrast, once T_{leaf} exceeded the threshold point of 36°C/5.92 KPa, it appears that a signalling mechanism was activated that induces stomatal opening and a corresponding increase in transpiration rate. Presumably stomatal opening is effected to reduce T_{leaf} and prevent the leaf from heating to 40°C which severely damages the leaves of Local and Soorab-96 and is lethal for Optic leaves (Fig.1d). The plants used in this study were well watered, but it is well established that the stomata of cereal crops grown in the field partially close during the hottest part of the day to conserve water (Robredo et al. 2007). It seems reasonable to conclude that stomatal aperture is regulated by a signalling mechanism for the conservation of tissue water when below a threshold point and a separate signalling mechanism to prevent T_{leaf} rising to 40°C above it. It would be interesting to establish whether the increase in g_s with T_{leaf} reported here is triggered directly by leaf temperatures exceeding 36ºC. It would also be interesting to investigate the response of stomata in a range of plants that are partially water limited and experiencing high leaf temperatures. In arid zones, crops in the field are probably faced with this dilemma, to reduce transpiration and conserve water and risk the rapid onset of thermal damage, or to maintain transpiration and reduce T_{leaf} but suffer the consequences of loss of turgor. A coherent strategy for developing crops that perform well in arid regions should be based on answering the question: What causes the suppression of growth and eventual death of plants in these regions? Increased water availability clearly ameliorates these effects but perhaps the onset of rapid thermal damage to the shoot tissues rather than water concentration in the shoot *per se* is the primary reason

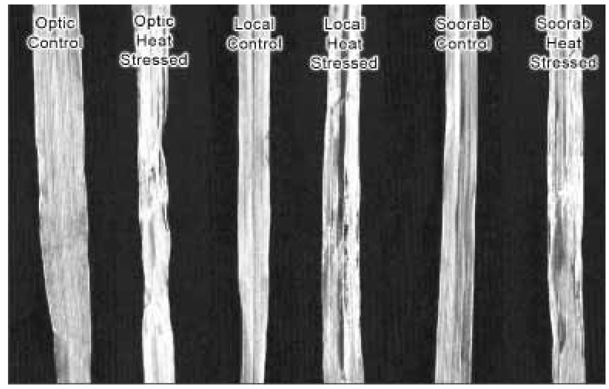

Figure 4. Images of leaves from three barley lines before and after heat stress. The paired images were taken from the same fully expanded 4th emergent leaf ~ 80 mm from the base of the leaf blade immediately before (Control) and 5 days after elevating Tleaf to 40.0ºC (± 0.2ºC) for three hours using a modified thermal cycler (see Materials & Methods). After heat stress plants were returned to the growth room (22ºC) to recover. In all cases leaves from line Optic showed far more extensive damage after 5 days than lines local and Soorab-96 (n = 8-12).

why some plants perform badly in these habitats. Strategies that focus on the genetic basis for heat tolerance or the capacity to recover from thermal injury may prove to be a fruitful avenue for developing crops with multiple traits for production in arid marginal lands.

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Potential options for improving and stabilizing wheat yields in the context of climate change in West Asia and North Africa

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Abstract

In the West Asia and North Africa (WANA) region, increasing water shortages due to more frequent droughts and the growing demand for water for industrial and domestic uses, will result in less water for crop production in the future. The crops that will suffer most from this are cereals because they are mainly grown in arid zones where opportunities for irrigation are very low. Approaches that can help reduce future water shortages and increase food production include the capture of more rainwater and better use of scarce irrigation water through the adoption of new improved technologies. Research conducted in the region has shown that supplemental irrigation (SI) using limited amounts of water at critical stages of crop growth and development, zero tillage (ZT) and improved cultivars, significantly increase and stabilize yields of wheat under rainfed conditions. Combining these technologies would improve and stabilize land productivity and help plants adapt to climate change. The objective of this study, conducted at ICARDA's research station at Tel Hadya in 2008/09, was to evaluate the additive effects of ZT, SI and genotype (G) on land and water productivity of bread wheat. The treatments tested were 'zero tillage' (ZT) vs. 'conventional tillage (CT)', 'supplemental irrigation (SI) at boot stage (35 mm) and milk stage (35 mm) vs. the rainfed regime (R)', and five improved genotypes of bread wheat ('Cham 6', 'Cham 8', 'Shuha', 'Cham 10', and 'Raaid-3'). Results showed that zero tillage improved leaf area index, specific leaf area, evapotranspiration, above ground biomass production, and biomass water productivity at the beginning of stem elongation generally in all the cultivars. At maturity, ZT under R, and CT under SI increased ET by 30 mm and 61 mm, respectively, as compared to CT under the R regime. The combination of ZT and SI, however, increased water use by 110 mm. Consequently, grain yield increased, on average, from 4515 kg/ha under CT-R, to 5929 kg/ha under ZT-SI combinations. The difference between the treatments ZT-R and CT-SI were not significant and the yields were 5063 kg/ha and 5244 kg/ha, respectively. All the genotypes responded positively, but differently, to ZT and SI, and Cham 6, Cham 8 and Shuha were the most responsive. Grain water productivity was not, however, affected by the tested treatments because both the yield and ET were increased by ZT and SI. These preliminary results showed that the combination of ZT and SI can improve the capture of rainwater and the use of supplemental irrigation, and hence increase land productivity under drought conditions.

Keywords: bread wheat, conventional tillage, drought, land and water productivity, rainfed, supplemental irrigation, WANA region, zero tillage

1. Introduction

Increasing scarcity of water, due to more frequent droughts and growing demand for water resources for industrial and domestic uses and for tourism, because of rising population and growing urbanization, will greatly reduce the water availability for agricultural production in the future. The cereal crops will suffer most firstly because in the event of drought these are the least to benefit from irrigation water and secondly because they are mainly grown in arid zones where the possibility of irrigation is limited. Consequent reduction in the cereal production will seriously affect the poor communities in the dry areas, because the cereals are their staple food.

Severe drought events and climate changes in the West Asia and North Africa (WANA) region would necessitate adoption of strategies that will cut water losses, enhance water use efficiency (WUE) and conserve natural resources of water to achieve sustainable increase in land and water productivity. Better management of irrigation water, and improved cultural practices and cultivars adapted to drought and rising temperatures would be important components of these strategies.

Plant breeders have always considered early flowering as one of the most important traits to select wheat genotypes that would adapt to water-limited environments. With climate change, this criterion will be more emphasized in the breeding programs as cultivars flowering earlier would be needed to escape terminal drought and heat stress. However, plants that flower early may not produce enough biomass to set a large number of seeds needed for high yield (Fischer 1979). Plants that flower too late will have high seed abortion because of the heat stress and too little water left for post-flowering photosynthesis and remobilization of carbohydrates from the vegetative organs to the grains (Passioura 2006). Consequently, ensuring a balance between the photosynthetic source (vegetative biomass production) and sink (seeds production) under early flowering is an important strategy to increase and stabilize yields in the rainfed areas.

Both breeding and field management can play an important role in enabling the plants to capture more water and use it more efficiently under stressed environments. So, in addition to the selection of varieties that have the characteristics described above, other technologies such as early planting, facilitated by zero tillage (ZT), can help the plants take advantage from the early rains and escape terminal drought and heat stresses. Moreover, zero tillage can also reduce loss of rainwater by evaporation and increase its use in transpiration early in the season. This can stimulate more early growth and hence increase the source size (vegetative biomass production) at flowering. Lopez-Castaneda (1994) showed that increase in leaf area development, or early vigor, of a cereal crop is associated with improvement in WUE early in the season. Faster leaf area development can increase crop water productivity (WP) by shading the soil surface to reduce evaporation and increasing transpiration when vapor pressure deficits are low. In addition to the improvement in early growth and water use by zero tillage, many scientists have shown its positive effect on yield and WP of wheat (Mrabet 2000a, 2000b; Cantero et al. 2007).

Supplemental irrigation (SI) can offset the water deficit late in the spring, increasing the soil moisture supply during the post-anthesis period and thus reducing the seeds abortion and improving seed size. Research conducted in dry areas (Oweis and Hachum 2006; Karrou and Boutfirass 2007) showed that SI can improve significantly the WP and save the resource without reducing land productivity. Oweis et al. (1999) demonstrated that WP of wheat under SI (given after heading) was as high as 2.5 kg grain per cubic meter of water, as compared to 500 g under rainfed conditions and 1.0 kg under full irrigation.

To harness full benefit of increased moisture supply under ZT and SI, it is important to use cultivars that are adapted to these agronomic systems. Laaroussi (1991) and Boutfirass (1997) did demonstrate large variations in the yield and WUE of different cultivars grown under rainfed and SI conditions in the semi arid rainfed areas of Morocco. Hall and Cholick (1989) and Ciha (1982) found that the grain yield ranking of wheat cultivars changed depending on the tillage systems, including ZT.

Although the positive effects of SI at critical stages of growth of wheat crop and of ZT on the sustainability of productivity in rainfed areas have been demonstrated in the past, information on the effect of combining these two variables and using more adapted improved varieties has not yet been much investigated. Hence, this study was undertaken.

2. Materials and methods

The experiment was carried out in the 2008/09 cropping season at Tel Hadya station of ICARDA, in northern Syria (36º01’N.36º 56’E; elevation 284 m asl). The long-term mean annual rainfall here is 320 mm, with considerable year to year variation (from 200 mm to over 500 mm). The soil is over 1 meter deep and fine textured (Ryan et al. 1997). It is classified as montmorillonitic, thermic Calcixerollic Xerochrept. It has good structure and is well drained, with a basic infiltration rate of about 11 mm/hr. The mean soil moisture content in the top 100 cm of the soil (by volume) is about 48% at field capacity and 24 % at the permanent wilting point.

The treatments tested were: tillage (conventional tillage vs. zero tillage), water regime (rainfed vs. supplemental irrigation) and bread wheat genotypes (5 cultivars). They were tested in a split-split plot design, with tillage as the main plot, water regime as the sub-plot, and genotypes as the sub-sub-plot, with 3 replications. In the zero-till (ZT) plot, seeds were sown directly with a no-till drill without any previous soil cultivation. On the conventional tillage (CT) plot, the soil was plowed twice with an offset disk, followed by a roll-packing operation. Rainfed (R) plots received only the water from rainfall, while the supplemental irrigation (SI) plots received, in addition, 35 mm irrigation water at boot stage and 35 mm at milk stage. The genotypes tested were 'Cham 6' (V1), 'Cham 8' (V2), 'Shuha' (V3), 'Cham 10' (V4) and 'Raaid-3' (V5). The sowing was done 17 November 2008 @ a seeding rate of 140 kg/ha. At the time of sowing, 80 Kg P/ha as Superphosphate and 60 Kg N/ha as urea (46% N) were applied. At the stage of stem elongation, a top dressing of 30 Kg N/ha as urea was done.

The measurements taken were above ground dry matter, leaf area index (LAI) and specific leaf area (SLA) and biomass water productivity at the beginning of stem elongation and grain yield and grain water productivity at harvest. SLA is the ratio of the leaf area to leaf dry matter. Water productivity was calculated as the ratio of dry matter or grain yield to evapotranspiration (ET). Actual ET was determined at 3-4 leaf stage, beginning of stem elongation, anthesis, milk and dough stages of grain, and at harvest, by studying changes in moisture content in different soil layers (at 0-15, 15-30, 30-45, 45-60, 60-75, 75-90, 90-105, 105-120, 120-135 and 135-150 cm) using a neutron probe. ET was calculated using the water balance equation. Data were analyzed using SAS (1997).

3. Results and discussion

3.1. Early growth and water use

Early vigor and rapid development of ground cover can reduce rainwater loss by evaporation and produce enough biomass necessary for supporting the onset and growth of grains. Rebetzke et al. (2004) defined greater early vigor as an increase in seedling leaf area index (LAI) and it is partly associated with specific leaf area (SLA). Our data show that zero tillage (ZT) gave higher LAI (Table 1) and SLA (Table 2) at stem elongation than conventional tillage (CT). The increases were however small and statistically non-significant. Total above ground dry matter (Table 3) was, however, affected significantly by the tillage. The values increased from 179.9 kg/ha with CT to 233.3 kg/ha with ZT. Passioura (2006) also observed such increase in early growth and attributed it to the early planting of winter crops , made possible by zero-till planter, when soil and air are still warm, leading to good canopy cover during late autumn

Table 1. Effect of zero-tillage and genotype on leaf area index of bread wheat at stem elongation.

	Conventional tillage	Zero tillage	Mean
Cham 6	3.33	4.14	3.74
Cham 8	1.69	2.85	2.27
Shuha	1.74	2.43	2.09
Cham 10	2.26	3.22	2.74
Raaid 3	2.69	3.61	3.15
Mean	2.34	3.25	
LSD			0.55

T and TxG effect: not significant; G effect: highly significant

Table 2. Effect of zero-tillage and genotype on specific leaf area (cm^2/g) of bread wheat at stem elongation.

	Conventional tillage	Zero tillage	Mean
Cham 6	216.3	243.8	230.1
Cham 8	200.2	217.9	209.1
Shuha	179.2	198.6	188.9
Cham 10	198.6	225.5	212.1
Raaid 3	220.3	246.6	233.4
Mean	202.9	226.5	
LSD			12.3

T and T x G effect: not significant; G effect: highly significant

Table 3. Effect of zero-tillage and genotype on above ground dry matter (kg/ha) of bread wheat at stem elongation.

	Conventional tillage	Zero tillage	Mean
Cham 6	2435	2745	2590
Cham 8	1309	2118	1713
Shuha	1482	1953	1718
Cham 10	1834	2424	2129
Raaid 3	1935	2422	2179
Mean	1799	2333	
LSD	for T means - 53.4 for G means - 373		

T and G effects: highly significant; G x T effect: not significant and winter and thus less evaporative losses from the soil surface.

Our results also showed that the effect of the genotype was highly significant for all the attributes of early growth. But there was no interaction between tillage and genotypes and all genotypes showed more or less similar improvement by ZT over CT. Cham 6 was the best. It was followed by Raaid-3 and Cham 10. Rebetzke et al. (2004) showed large genotypic differences for SLA in wheat and inferred that genotypes with higher leaf area but with the same SLA should have greater photosynthesis per unit ground area.

Despite the importance of early growth described above, there is a need for balancing it with the available moisture supply to increase and sustain yields in the rainfed areas. An adequate amount of dry matter production is necessary to support the development of the sink (grains) (Fischer 1979); however, excessive early vegetative growth may deplete more rapidly soil moisture and result in too little available water during grain filling (Passioura 2006). Consequently a balance between the source and sink development and use of available water is important.

The amount of water used (ET) and water productivity (WP) at stem elongation are presented in Tables 4 and 5. The difference between tillage methods for ET was significant and ZT increased water use by 10% over CT. Similarly, the WP was increased by 15%; however, the difference between the two tillage systems was not significant. The increase of both ET and dry matter due to ZT was probably due to more transpiration. Fischer (1979) showed that faster leaf area development should increase crop water use efficiency by increasing transpiration when vapor pressure deficits are low. The uptake of more water might be related to an early root growth under ZT conditions. Angus et al. (2001) opined that crops that are vigorous when young tend to extract more water from the subsoil, presumably because their roots grow deeper.

All the genotypes had higher ET with ZT as compared to CT, except Raaid-3 which showed no difference between the two tillage systems. However, in the case of WP, more response, although not significant, was observed in Cham 8 and Raaid-3 than other genotypes. As described earlier for

Table 4. Effect of zero-tillage and genotype on ET (mm) of bread wheat at stem elongation.

	Conventional tillage	Zero tillage	Mean
Cham 6	94.3	103.1	98.7
Cham 8	84.5	97.3	90.9
Shuha	91.1	107.9	99.5
Cham 10	88.3	102.4	95.3
Raaid 3	95.9	95.9	95.9
Mean	90.8	101.3	
LSD	for T means - 10.3		

T effect: significant; G and G x T effects: not significant

Table 5. Effect of zero-tillage and genotype on biomass water productivity (kg per m^3 of water) of bread wheat at stem elongation.

	Conventional tillage	Zero tillage	Mean
Cham 6	2.60	2.67	2.63
Cham 8	1.55	2.17	1.86
Shuha	1.63	1.82	1.73
Cham 10	2.07	2.37	2.22
Raaid 3	1.99	2.53	2.26
Mean	1.97		
LSD			0.38

T and G x T effects: not significant; G effect: highly significant

growth parameters (LAI and dry matter), Cham 6, Raaid-3 and Cham 10 had also, on average, higher WP than the other genotypes.

3.2. Grain yield and water use at maturity

Grain yield per hectare as affected by tillage (T), supplemental irrigation (SI) and the genotype (G) is presented in Table 6. The analysis of variance (ANOVA) showed that the effects of SI, G, the interactions T x G and SI x G were highly significant. However, the effects of T and the interactions T x SI and T x SI x G were not significant; although zero tillage increased yield by 600 kg per ha as compared to the conventional tillage. The positive effect of ZT on wheat yield after different preceding crops has also been demonstrated by Hemmat and Eskandari (2004a, 2004b and 2006) in Iran, Mrabet (2000a, 2000b and 2008) in Morocco, and Vadon et al. (2006) in Tunisia. The higher rainfed crop yield in ZT than in CT in our study was probably due to the uptake of more water (30mm) under the former technique. This is in conformity with the finding of Passioura (2006) who demonstrated that capturing 30mm of additional water could be translated into an increased wheat yield of about 1 t/ha. However, negative effect of zero tillage on yield has also been noticed, for example in Syria (Pala et al. 2000 and Thomas et al. 2007). This might have been due mainly to disease infestation (Thomas et al. 2003), which was not observed in our experiment.

All the genotypes responded positively to ZT and to SI, but differently, except Raaid-3 for which the difference was not significant. The genotypes Cham 6 and Cham 8 tended to respond more to the ZT and SI. Moreover, for these 2 genotypes, the combined effect of these two techniques was synergistic. The genotypes Cham 10 and Raaid-3 were not much affected by this combination.These results are in line with the genotypic variations observed by Laaroussi (1991) and Boutfirass (1997) under SI and Hall and Cholick (1989) and Ciha (1982) under conservation tillage.

Table 7 shows ET at maturity under the different treatment combinations. There was no effect of tillage method; however, the effects of SI, T x SI and T x G were significant. Supplemental irrigation increased ET from 342 to 403mm under CT and from 372 to 452mm under ZT. These increases amounted to 61 and 80mm, respectively. The genotypes responded differently to tillage. Cham 10 used the highest amount of water under ZT as compared to CT and it was followed by Shuha. ET of Cham 6 and Raaid-3 were less affected by the tillage method; and Cham 8 was least responsive.

Water productivity was affected significantly only by the genotype (Table 8). However, the genotypes tended to respond differently to zero tillage. Cham 6, Cham 8 and Shuha had the highest WP under ZT; while Cham 10 and Raaid-3 tended to use water more efficiently under CT. The genotypes that used more water under ZT had their WP reduced. Cantero et al. (2007), Hemmat and Eskandari (2006) and Bouzza (1990), however, showed a positive effect of ZT on WP.

Conclusions

It is clear from this preliminary study that zero tillage is a technique that can improve the early vigor of the seedlings and ensure a good canopy cover that reduces the loss of rainwater by evaporation

Table 6. Effect of zero-tillage, supplemental irrigation and genotype on grain yield (kg/ha) of bread wheat.

	Conventional tillage		Zero tillage		Mean
	R	SI	R	SI	
Cham 6	4307	5020	4920	6270	5130
Cham 8	4810	5710	5570	6950	5758
Shuha	4720	5800	5730	6520	5693
Cham 10	4650	5380	5610	5980	5405
Raaid 3	4090	4320	3490	3920	3954
Mean	4515	5244	5063	5929	
LSD	for SI means - 420 for G means - 375				

T effect: not significant; T x SI and T x SI x G effects: not significant, T x G and SI x G effects: significant

Table 7. Effect of zero-tillage, supplemental irrigation and genotype on ET (mm) of bread wheat at maturity.

	Conventional tillage		Zero tillage		Mean
	R	SI	R	SI	
Cham 6	306	399	335	428	367
Cham 8	374	398	356	407	384
Shuha	330	407	358	479	393
Cham 10	339	395	406	523	399
Raaid 3	359	416	404	419	416
Mean	342	403	372	452	
LSD	for SI means - 20 for G means - 32				

T; SI x G and ZT x SI x G effects: not significant , SI; G; T x G and T x SI effects: significant

Table 8. Effect of zero-tillage, supplemental irrigation and genotype on grains water productivity (kg per m^3 of water) of bread wheat at maturity.

	Conventional tillage		Zero tillage		Mean
	WR1	WR2	WR1	WR2	
Cham 6	14.0	12.6	14.9	14.6	14.0
Cham 8	12.9	14.3	15.9	17.1	15.0
Shuha	14.3	14.4	16.2	13.9	14.7
Cham 10	13.6	13.6	14.0	11.5	13.2
Raaid 3	11.4	10.4	08.6	09.4	10.1
Mean	13.2	13.0	13.6	13.1	
LSD					1.4

G effect highly significant; rest of the effects not significant and increases transpiration. There are significant genotypic differences in response to the ZT and hence there is possibility to select varieties that are more adapted for this tillage system. Combining ZT and late season supplemental irrigation improved water uptake and land productivity. Further studies are needed to confirm these results.

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Breeding food legumes for enhanced drought and heat tolerance to cope with climate change

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Abstract

Frequent droughts and fluctuations in temperature are inevitable under climate change (CC). For sustainable food and nutritional security, cereal-based farming systems need to incorporate food legumes best suited to CC. Chickpea, faba bean, lentil and grasspea, are important cool-season food legumes commonly grown under rainfed conditions in non-tropical dry areas worldwide. Drought and heat stresses, especially after the onset of flowering, are common causing substantial yield losses. ICARDA lays emphasis on improving the yield potential and stability of these crops by incorporating genes for drought and heat tolerance, productivity and resistance to key diseases to keep ICARDA and NARS breeding programs make sustained progress. ICARDA's main research station at Tel Hadya, with 350 mm average rainfall, and the other two substations, Breda (250 mm rainfall) in Syria and Terbol in the Bekaa valley in Lebanon (450 mm rainfall), provide the opportunity to evaluate germplasm and elite advanced progenies under different moisture regimes. To adapt to CC, crop improvement efforts are focused on identifying drought and heat tolerant genotypes using different screening methodologies, dissecting these complex traits into their components, and determining genes/QTLs for each component to pyramid them in good agronomic background, using both conventional and molecular approaches. The methodologies currently used to screen chickpea, lentil and faba bean germplasm/ improved materials for tolerance to heat stress include delayed sowing to let the flowering period of the crops coincide with the period of high temperature shocks, while for drought tolerance a late planting on receding soil moisture and at low rainfall sites is adopted. These methodologies have helped to improve germplasm and are being supplemented with genomic research to generate knowledge that may further help in understanding these stresses. In this paper, we discuss breeding strategies for adaptation of food legume crops to cope with stresses under the climate changes.

Keywords: adaptation, climate change, drought, food legumes, heat, mitigation.

1. Introduction

Chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.), lentil (*Lens culinaris* ssp. *culinaris*), and grasspea (*Lathyrus sativus* L.) are important cool-season food legume crops commonly grown under the fragile agro-ecosystems in the non-tropical dry areas where drought and temperature extremities are of common occurrence with varying intensity and frequency. The intensity, frequency and uncertainty of occurrence of these stresses is predicted to increase, under climate change with adversely affecting their production unless these crops are manipulated genetically to adapt to the production environment and/or the environment is altered agronomically to suit the crop requirement. These crops play an important role in sustainability of the crop production system by fixing atmospheric nitrogen in association with *Rhizobium* bacteria and enhancing the activity of other beneficial soil microbs. Being rich in protein and micronutrients, their role as food and feed in nutritional security and health is also well recognized (Ali and Kumar 2009).

Food legume crops are severely affected by heat and drought in dry areas. Global climate models predict that climate change will most likely have both positive and negative impacts on these crops. Some of the beneficial effects, for example in faba bean, include increased water use efficiency, photosynthesis and yield, and decreased stomatal conductance (Khan el al. 2007).

The negative effects include the likely change in the pest spectrum, appearance of new pests and races in traditional areas and their spread to newer areas where their existance had never been reported; for example, *Orobanche* in Ethiopia, Bruchids infestation in China, *Helicoverpa* pod borer infestation in chickpea in WestAsia and North Africa (WANA) and global distribution of rust in faba bean in the recent past. With rise in temperature, air aridity and water stress, root diseases such as *Fusarium* wilt and dry root rot are expected to expand in chickpea, faba bean, and lentil and rust in faba bean growing regions. However, *Ascochyta* blight, Botrytis grey mold and Chocolate spot may become minor diseases in future due to more dry environments. Emergence of *Stemphylium* blight as a major disease of lentil in South Asia is a case of shift in disease spectrum due to climate change. However, the most severe negative impacts are the direct effects of heat and drought stresses, which can cause total crop failure.

Faba bean is known to be sensitive to drought (Amede and Schubert 2003; McDonald and Paulsen 1997) and grows well in environments with more than 450 mm seasonal precipitation whereas chickpea can successfully be grown in areas with 300-450 mm and lentils with 250-300 mm rainfall. Grasspea is the most drought hardy crop and can thus be grown even with 200 mm rainfall. Water stress can cause heavy yield losses in these crops depending on the crop stage, severity of drought occurrence, evaporative demand of the atmosphere and moisture holding capacity of the soil (Erskine et al. 1994; Subbarao et al. 1995; Wery et al. 1994).

Heat stress even for a few days during the flowering and pod filling stages drastically reduces the seed yield in the grain legume crops (Kumar and Abbo 2001; Siddique et al. 2002) because of damage to reproductive organs (Hall 2004), accelerated rate of plant development (Gan et al. 2004) and shortened period of reproductive growth (Angadi et al. 2000). High temperatures during reproductive development often negatively impact pollen viability and fertility (Hall 2004), floral bud development (Prasad et al. 2002), seed filling (Boote et al. 2005) and seed composition (Thomas et al. 2003).

Atmospheric temperatures are expected to increase in future due to climate change (Cutforth 2000). This may increase the frequency of heat stress for annual crops including chickpea, faba bean and lentil. Temperature and drought stresses may occur simulteneously with confounding effect on the productivity. This paper reviews work on adaptation and mitigation strategies under heat and drought stresses for ICARDA's mandated food legume crops.

2. Production environment

The major geographical regions of chickpea, faba bean, lentil and grasspea cultivation are South Asia, China, West Asia and North Africa, Sub-Saharan Africa, North Great Plains of North America, South America and Australia. Characterization of drought patterns and heat stress in these regions is an important step in designing strategies for improving drought and heat tolerance (Subbarao et al. 1995).

In South Asia, which accounts for more than 60% of the global food legume production, these crops are grown in the post-rainy season on residual moisture and therefore, early withdrawal of rains adversely affects their establishment. They also expecience sudden rise in temperature and depleting soil moisture at grain filling stage, causing forced maturity. Cultivars that mature relatively early are usually less affected by the environments. Thus, short duration cultivars with rapid grain filling characteristic have been the major breeding target to avoid substantial terminal stress (Summerfield 1981).

In the Mediterranean environments of the WANA region, intermittent drought throughout the crop season and terminal drought and heat stress are common (Silim et al. 1993; Wery et al. 1994; Siddique et al. 1999; Ricciardi et al. 2001; Canci and Toker 2009). Generally, the amount and distribution of the rainfall during the crop season are the major determinants of seed yield in the WANA region, where these crops are mostly grown rainfed. Lentil yield can be increased upto 20-60% by making more efficient use of available moisture and by avoiding heat stress (Oweis et al. 2004). High temperature hastens the growth and development processes reducing the life cycle, thus productivity. Seed size and shape are also adversely affected by high temperatures, accentuating economic losses. Spring planted chickpea and lentil crops frequently experience heat stress and terminal drought in the latter part of the growing season, seriously reducing the yields.

Effects of these two stresses are very difficult to separate. Crops planted in the winter may develop and mature sufficiently early to avoid the most severe heat and drought stresses. This is simply an escape mechanism. Development of chickpea, faba bean and lentil varieties tolerant to heat stress to a certain level of temperature (up to 350C) is the present strategy to adapt these crops to rising temperature during the grain filling period.

3. Germplasm evaluation and enhancement

ICARDA's genebank holds approximately 38,000 accessions of chickpea, faba bean, lentil and grasspea collected from different parts of the world. The breeding programs use these collections to search for sources of tolerance to drought and heat. ICARDA's recently developed foccussed identification germplasm strategy (FIGS) is improving the efficiency with which the plant genetic resources can be utilised from *ex situ* collections. The best bets germplasm for drought and heat tolerance is thus quickly identified for adaptation to stress environments. Part of this germplasm has been evaluated for traits associated with drought and heat tolerance such as short crop duration, root and shoot traits, harvest index, resulting in identfication of useful donors for these traits.

3.1. Screening techniques

The efficiency of a screening technique depends on its ability to reproduce the most probable conditions of the stress in the target environment (Wery et al. 1994). It requires characterization of the most probable stress in its actual position in the plant cycle and its reproduction in conditions where screening of a large number of genotypes can be made. These two steps are essential for representativeness and reproducibility of screening technique. The next step is to define the plant traits required for target environment before screening test can be made. The terminal heat stress is frequently associated with soil moisture stress and occurs at reproductive stage of these crops.Therefore, germplasm must be planted at appropriate times in the target location so as to let the occurrence of stress coincide with the critical crop stages.

To develop drought and heat tolerant germplasm, experiments on faba bean, chickpea and lentil are conducted at locations that cover water and heat gradients common in the region. The locations include Tel Hadya (with a long term average rainfall of 350 mm) and Breda (250 mm raifall) in Syria, and Kfardan (300 mm raifall with late cold) and Terbol (550 mm rainfall) in the Bekaa valley of Lebanon. Thus, food legume breeding material (germplasm and elite progenies) can be evaluated under large moisture and temperature gradients. ICARDA's main station at Tel Hadya experiences scanty rainfall with frequent drought events (Fig. 1) and high temperatures between mid May and September (Fig. 2) as is evident from the data of last 33 years. Sowing of heat and drought screening trials is delayed to late March to allow the flowering and pod development stages to be exposed to high temperature and terminal drought in Tel Hadya. At the Terbol research station , sowing

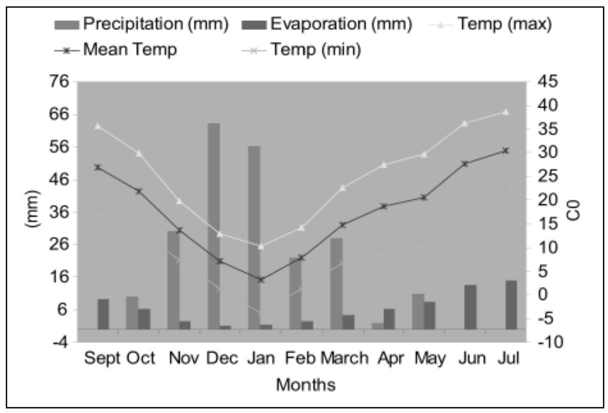

Figure 1. Mean (33 years) monthly precipitation, evapotranspiration and other climatic parameters at Tel Hadya research station of ICARDA in northern Syria.

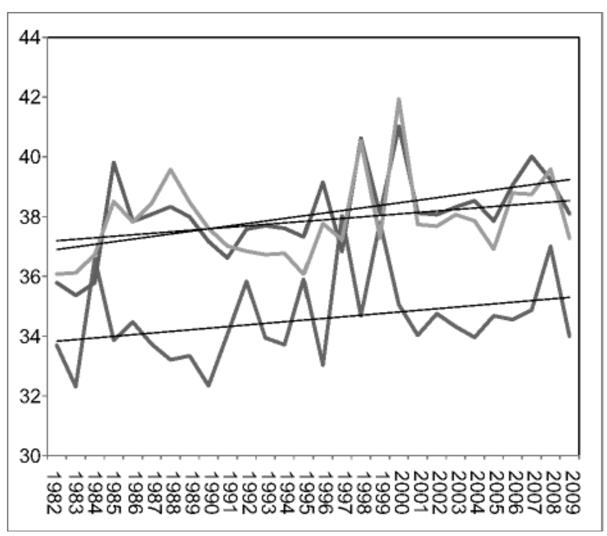

Figure 2. Maximum temperature registred during summer at Tel Hadya (red), Breda (green) and Terbol (blue) stations of ICARDA, 1982 to 2008.

is delayed till the middle of June and the material is grown under two moisture regimes (full irrigation and water stress conditions). The test entries are planted in rows with repetitive checks (local, susceptible and tolerant).

In case of chickpea, several lines are planted each year and scored for drought tolerance using scale 1 (highly tolerant) to 9 (highly susceptible). Out of 4,000 chickpea genotypes tested at Tel Hadya in 2008, an extremely dry year with only 220 mm rainfall, only 157 genotypes were classified as highly tolerant to moisture stress (Fig. 3). In faba bean, out of 600 lines tested in 2009, only 6 were highly tolerant to heat and drought (Fig. 4). Evaluation of lentil lines under delayed planting in field and wooden boxes in plastic house has resulted in identification of putative tolerant genotypes for heat (ILL 3597, Sel # 33108, 33109, 33110 and 33113) and drought (ILL1878, ILL 6002, ILL 759 and ILL 6465). These results indicate that sources of tolerance to heat and drought are available in the germplasm of cultivated species, which can be used in the breeding programs to introgress gene(s)/QTLs assciated with heat and drought tolerance into agronomically superior background for target environments.

Breeding for drought and heat tolerance in these crops is largely based upon creating, evaluating and selecting the right combination of alleles. This is done empirically by 'selection – hybridization – selection' cycle with final evaluation of promising genotypes in multi-environment trials within the Internationl Nurseries Program of ICARDA to identify superior cultivars with better performance in the target environments. This task of empirical selection becomes difficult because of the presence of GxE interaction, which masks up substantial part of phenotypic expression of quantitative traits like heat and drought tolerance in terms of grain yield, resulting into slow progress in genetic improvement for these traits (Malhotra and Singh 1991).

Two major breeding strategies are followed to alleviate the moisture and heat stress: one by breeding for traits that enable plants to escape stress period and another by breeding stress tolerant genotypes. Early plant vigor, fast ground cover and large seed size besides high root biomass, long and deep root system, high leaf water potential and small leaflets are some of the attributes

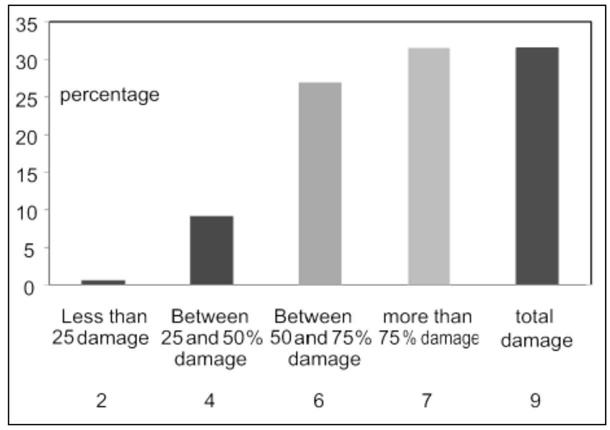

Figure 4. Variation in the response to heat and drought in 600 faba bean lines evaluated in 2009 on a 1 to 9 rating scale.

showing significant association with drought tolerance, whereas high harvest index, large number of pods per unit area and high seed mass along with early maturity are associated with drought escape (Passioura 1982).

3.2. Physiological traits

Analyzing the responses of the physiological determinants of yield to water and heat stresses can be very useful in breeding for high yield and stability under such stresses. A physiological understanding of plant responses to drought assists breeders in the development of high yielding varieties for water-scarce environments (Richards 2006). Food legumes germplasm which show stability of performance under hostile environments maintain some physiological components of tolerance to environmental stresses (Blum 1984). Understanding the underlying physiological basis of drought tolerance in food legumes could be helpful in identifying genotypes suitable for water-limited environments (Nerkar et al. 1981).

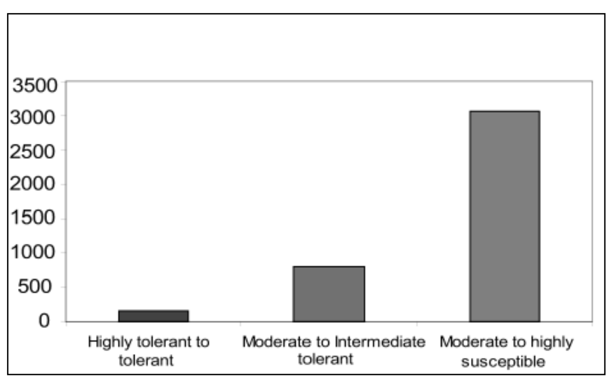

Figure 3. Variation in the response to heat and drought in 4000 Kabuli chickpea lines evaluated in 2009.

Table 1. Correlation coefficient between yield per plant, pod per plant and fluorescence indices in chickpea.

Fv/Fm1					
Fv/Fm2	0.06				
Fv/Fm3	0.05	0.50			
Pods/plant	-0.19	-0.29	-0.52		
Yield/plant	-0.13	-0.28	-0.42	0.94	
	Fv/Fm1	Fv/Fm2	Fv/Fm3	Pods/plant	Yield/plant

Note: Fv/Fm^1, Fv/Fm^2 and Fv/Fm^3 represent chlorophyll fluorescence measured at three intervals.

Direct measurement of physiological processes involved in drought tolerance shows promise if a large number of genotypes can be screened (Wery et al. 1994). Increased crop performance may be achieved through improvements in water use efficiency and harvest index. Various physiological attributes in faba bean have been examined that may be useful in developing selection techniques for tolerance to drought stress (Amede and Schubert 2003; Khan et al. 2007). Regulation of cellular turger pressure and hydration through osmotic adjustment has shown to increase yield potential under water-deficit environments. However, physiological traits, in general, have seldom been used successfully as selection criteria in breeding programs because of the lack of a simple repeatable large-scale screening technique.

Use of SPAD chlorophyll meter, NDVI index and carbon isotope discrimination methods have been in use to derive better understanding of drought physiology. Carbon isotope discrimination constitutes a simple but reliable measure of WUE. Measurement of chlorophyll fluorescence is another simple and reliable technique for screening germplasm for drought traits. Recent studies in chickpea showed significant correlation of chlorophyll fluorescence (Fv/Fm3) with yield and yield components (Table 1). In faba bean, evaluation of 11 lines for biomass (NDVI) and chlorophyll fluorescence showed that the two lines, namely DT9013/05/06 and DT9008/05/06 had tolerance to drought, lower biomass and higher accumulation of chlorophyll in the leaves as compared to other tested lines (Fig. 5).

3.3. Breeding for earliness

Phenological traits, which increase the relative amount of water used during grain filling or adjust the crop cycle to the seasonal pattern of rainfall are useful in drought prone environments.

Although one cannot expect any single trait to determine yield under water and heat stresses in view of the variability of stress and complexity of yield manifestation, early growth vigor has shown strong correlation with biomass and seed yield in lentil and is of practical value in predicting final yield under short duration environment (Silim et al. 1993). Short duration varieties of lentil show a typical drought avoidance strategy at the reproductive stage when high temperatures and water deficits induce rapid senescence and early maturity (Erskine et al. 1994; Shrestha et al. 2006a). Under short season rainfed environments of South Asia, the superior performance of lentil genotypes from South Asia and derivatives from crosses between South and West Asian lentils has been correlated with rapid canopy cover, early phenology and high harvest index (Shrestha et al. 2005). Therefore, genotypes with rapid ground cover, early phenology, a prolonged flowering and podding period leading to increased dry matter production, more pods, high harvest index, efficient water use and large seeds are targeted to adapt to drought and heat stresses. Most of the progress in breeding for drought escape to date has been made by development of short duration lentil varieties such as 'Precoz', 'Idlib 3', 'Bakaria', 'BARI M4', 'BARI M5' and 'BARI M6' without compromising yield level. Studies showed that Precoz possesses a major gene 'Sn' for earliness and produces early and extra early transgressive segregants which can fit well in drought escape strategy (Sarker et al. 1999). In case of chickpea, widely known drought tolerant varierty 'Gökçe', also escapes moisture stress through early flowering and maturity (Ismail et al. 2006).

3.4. Breeding for yield and yield components

A better understanding of the effects of drought on plants is essential for achieving success in

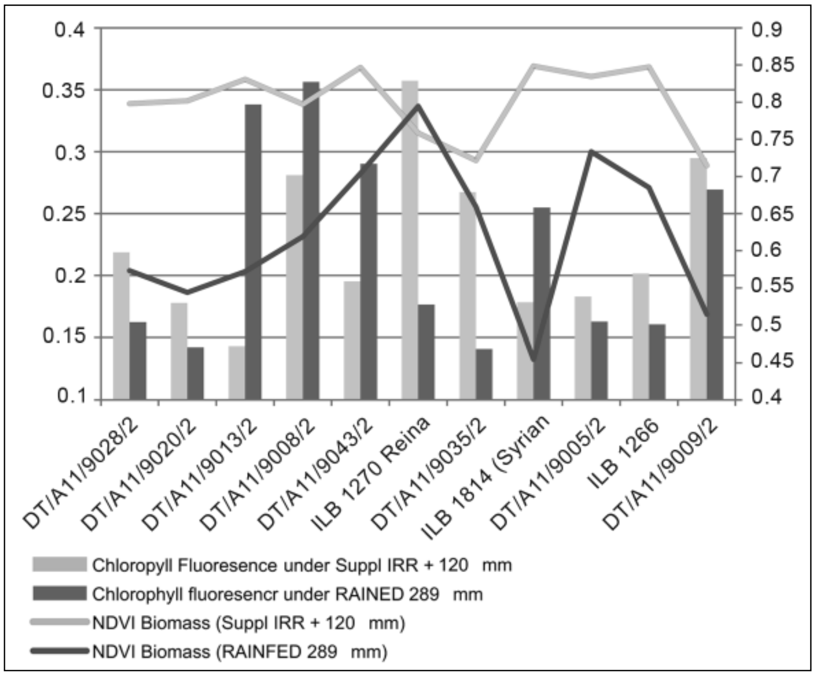

Figure 5. Variation in chlorophyll fluorescence (left axis) and NDVI (right axis) in 11 faba bean genotypes evaluated under rainfed (289 mm rainfall) and supplementary irrigation (120 mm) conditions.

breeding efforts for agriculture under climate change (Chaves et al. 2003). The keystone of drought resistance for plant breeders and crop physiologists is tailoring the phenology and physiology of a crop to its environment to manage well its water economy (Passioura 2007). Harvest index is strongly reduced by the terminal drought in grain legumes. Augmenting the contribution of carbohydrate reserves accumulated during vegetative growth to grain filling may be worthwhile in harsh environments. As lentils, chickpea and faba bean have indeterminate growth habit, water deficits at the reproductive stage affect both vegetative and reproductive development by reducing leaf area, dry matter production, number of branches and, hence, the number of flowers, pods and seeds.

Under water deficit conditions, the number of pods and seeds and seed size are most important traits related to seed yield in these crops (Shrestha et al. 2006b; Canci and Toker 2009). Number of pods and secondary branches per plant, seeds per pod, plant height and straw yield are reported to have positive and significant correlation with grain yield in lentil (Erskine 1983; Singh and Singh 1991; Pandey et al. 1992). Thus, selection for increased seed yield would not adversely affect straw yield. Therefore, early maturing plants having early growth vigor and higher number of pods are selected for the short season environments to enable the crop to escape terminal stresses.

Clements (1997) identified 'ILL 590' and 'ILL 7200' as drought tolerant lentil genotypes because of their short duration, rapid biomass and leaf area development, and high photosynthetically active radiation interception under drought situation in the Mediterranean climate. Evaluation of promising lentil lines derived from crosses involving 'ILL 6002' in target environments has resulted in the identification of Sel # 34101, 34109 and 34115 with superior grain yield. These lentil selections in spite of almost equal biological yield as in local checks could give higher yield due to better harvest index and matching crop duration with the water availability (Fig. 6).

Another strategy adopted for developing drought tolerant genotypes is to test elite lines across an artificially created water gradient. This technology

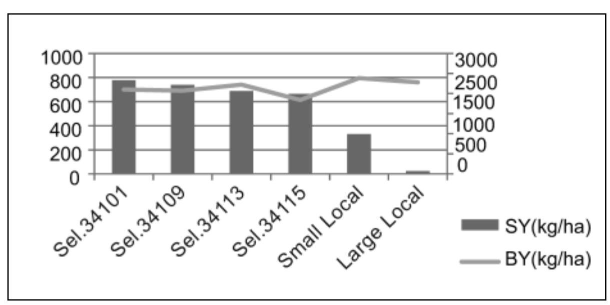

Figure 6. Grain and biomass yield performance of lentil genotypes under 178 mm precipitation at Breda station of ICARDA in 2008.

can help in selecting the genotypes that give acceptable yield under water stress and have capability to give higher yield when sufficient water becomes available. Fig.7 shows the response of chickpea lines under different moisture regimes (rainfed, 50% and 100% water holding capacity). Chickpea cultivars, 'Ghab 4' and 'Ghab 5' released in Syria and 'FLIP98-22C' showed highest yield under rainfed conditions and responded positively to improved moisture supply.

Similarly, success was obtained with faba bean also using similar approach (Link et al. 1999). Out of 11 genotypes of faba bean tested at two ICARDA sites having different amount and distribution of rainfall, two genotypes, 'DT/9013/05/06' and 'DT9008/05/06', exhibited better response to water availability (Fig. 8).

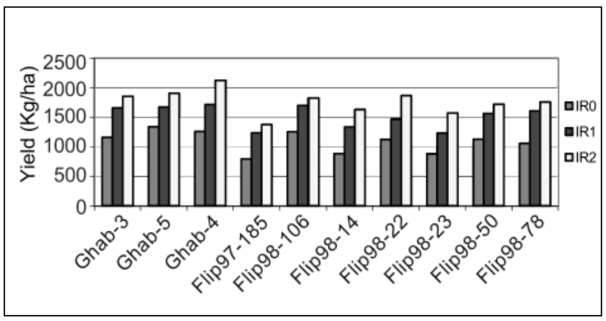

Figure 7. Grain yield response of some drought tolerant chickpea genotypes to different levels of irrigation during 2001-2005 at IR0 (rainfed, no irrigation), IR1 and IR2 (50% and 100% of the water holding capacity of the soil, respectively).

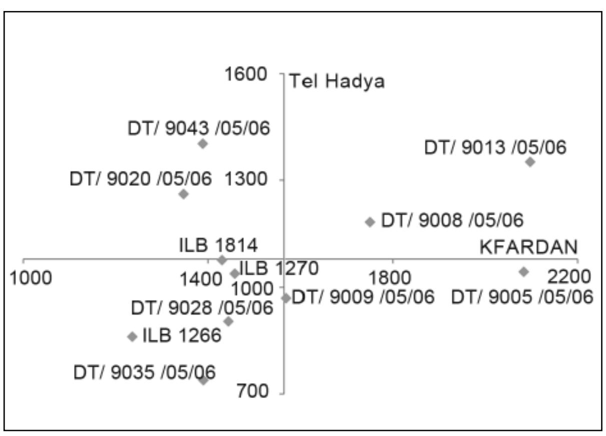

Figure 8. Evaluation of faba bean lines under two rainfed environments, Kfardan (420 mm rainfall) and Tel Hadya (289 mm rainfall), in the 2008-2009 growing season. The vertical and horizontal lines indicate seed yield (kg/ha) at Tel Hadya and Kfardan respectively.

3.5. Breeding for root traits

Among several traits imparting drought tolerance, a deep root system enhances the plant's capacity to extract water from the lower soil strata and helps avoid water stress. We evaluated 40 lentil genotypes for shoot and root characteristics and their association with drought tolerance over two crop seasons (Sarker et al. 2005). Significant genetic variability for stem length, taproot length, total root length, stem weight, total root weight, and lateral root number was observed (Table 2). Stem length, taproot length and lateral root number were highly correlated amongst themselves and with yield. The study resulted in identification of 'ILL 6002', which exhibited significantly superior root and shoot traits and yield and was therefore selected for breeding drought tolerant cultivars. In another study, 43 lentil genotypes (comprising released cultivars, promising breeding lines and germplasm accessions) showed significant genetic variation for root length, seedling vigor, biomass, plant height, harvest index, grain yield and SPAD value (Kumar et al. 2009). Some of the genotypes such as 'ILL 8114' had long root length (82 cm) coupled with high SPAD value (43.5), high biomass (6.7 g), grain yield (2.2 g) and harvest index (33%). In general, genotypes with root length varying from 54 to 62 cm had average biomass and harvest index (26-35%). Root length showed significant positive correlation with early vigor and SPAD value and therefore can be used as a selection criteria for identifying drought tolerant genotypes in lentil. The contrasting genotypes are being used for developing population to map QTLs responsible for various traits imparting drought tolerance.

In chickpea, genotypes differed in terms of root length, root length density, root weight density and root length to weight ratio at every 20 cm soil layer up to 100 cm depth in response to water deficits. Consideration of an efficient root system is also very important as the advantage of large root systems can be negated by associated low harvest index, presumably due to the lack of assimilates available for grain growth. A restricted root system is important in environments where crop growth termination is usually required prior to fall frost like Canada or where water table is shallow.

Table 2. Genetic variation for root and shoot traits in 40 accessions of lentil (Sarker et al. 2005).

Character	Minimum value	Maximum	Mean±SE
Stem length (cm)	4.7	11.9	8.4±0.13
Stem weight (g)	0.15	0.82	0.38±0.04
Taproot length (cm)	11.6	47.2	28.2±0.74
Lateral root number	16.0	50.0	26.1±0.73
Total root length (cm)	068	7.05	3.01±0.18
Total root weight (g)	0.12	0.92	0.35±003
Seed yield per plant (g)	0.16	0.95	0.46±0.05

4. Agronomic approach to mitigate drought

In the Mediterranean environments of WANA, lentil is usually grown in regions with 250-400 mm precipitation. However, the rainfall amount and distribution varies from season to season. The annual distribution is sometimes such that all rain events occur early in the season. If the rainfall is inadequate to allow plants to complete their life cycle, supplemental irrigation (SI) is necessary. In Syria, Hamdi et al. (1992) reported lentil yield to increase by 20 to 60% with two supplemental irrigations (SI). The study identfied genotypes 'ILL 241', 'ILL 5523' and 'ILL 5527' as promising under supplemental irrigtaion and 'ILL 1983', 'ILL 2501', and 'ILL 2526' under dry conditions. Oweis et al. (2004) indicated that grain and biomass yields in lentil increased as the moisture deficit was increasingly removed by SI. They showed that when SI was given to meet the 2/3 deficit in the moisture supply, the water productivity was maximum for both grain and biomass.

Early sowing increased lentil biomass production by 0.47 and 1.56 t/ha over normal and late sowing. However, the highest grain yield of 1.60 t/ha was obtained at the nomal sowing date. Grain water productivity with SI, however, increased when sowing was late in the season. Biomass water productivity, by contrast, increased with the early sowing – 1.79 (late), 1.97 (normal), and 2.05 kg/m^3 (early).

In 2009, we studied the effect of supplemental irrigation (SI) given at flowering as compared to the rainfed condition (228 mm seasonal rainfall) using 15 genotypes of lentil. The results (Table 3), in confirmity with the observations of Oweis et al. (2004), showed a significant positive effect of SI on grain yield and harvest index. SI increased grain yield from 609 kg/ha to 834 kg/ha and harvest index from 24.5% to 36.65%. Considering all the yield contributing traits together, four genotypes ('ILL 8068', 'ILL 10707', 'ILL 590' and 'ILL 6994') were identified to be the most promising both under SI as well as rainfed conditions. A positive correlation (r= 0.89**) was observed between grain yield and harvest index under rainfed as well as SI conditions (Table 4). Seed weight, harvest index, biological yield and grain yield were positively interrelated with each other under both conditions. This indicates that harvest index, seed weight and biological yield could be the target traits for getting genetic improvement in lentil grain yield under water stress environment.

Supplemetal irrigation also showed great improvement in the productivity of different chickpea genotypes grown at Tel Hady during spring of 2001 to 2005 growing seasons. The mean grain yield doubled with a single irrigation (see Fig. 7).

5. Future thrust

To date, breeding for drought and heat tolerance has been based principally on empirical selection for yield *per se*. However, this approach is far from being optimal since yield is characterized by low heritability and high genotype x environment interaction. Therefore, rapid genetic progress will directly depend on our ability to precisely target key traits and to identify and locate gene sequences controlling them. Physiological traits that contribute to improved productivity under moderate drought and heat conditions need to be the focus of the future research. A major limitation to genomics enabled improvement in these crops has been limited number of locus specific co-dominant markers and precise mapping and tagging of useful genes. However, recent development in molecular markers technology (SSR, SNPs) for

Table 3. Range of variability and heritability of different traits under rainfed and irrigated conditions in 15 accessions of lentil.

Character	Rainfed conditions			Irrigated conditions		
	Range of variation	Mean	Heritability	Range of variation	Mean	Heritability
Days to flowering	91-98	95	0.587	96-103	100	0.288
Days to maturity	126-129	127	0.547	119-129	123	0.249
Reproductive period	29-35	33	0.334	19-25	23	0.079
Biological yield (kg/ha)	1762-3240	2386	0.727	1668-3179	2260	0.151
Grain yield (kg/ha)	336-1081	609	0.577	540-1326	834	0.433
Harvest index (%)	11-40	24.50	0.520	21-45	36.65	0.379
100-seed weight (g)	2.85-4.45	3.55	0.763	2.70-4.35	3.41	0.443

Table 4. Simple correlation coefficient between different traits studied in 15 lentil genotypes grown under rainfed (228mm rainfall) and irrigated (30 mm additional water) conditions at Tel Hadya.

Character	DTF	DM	RP	BY	GY	HI	SW
Days to flowering (DTF)		**0.82****	**-0.58**	**0.57**	**0.50**	**0.27**	**0.20**
Days to maturity (DM)	0.55		**-0.01**	**0.34**	**0.45**	**0.14**	**-0.04**
Reproductive period (RP)	-0.84**	-0.01		**-0.51**	**0.34**	**-0.26**	**-0.41**
Biological yield (kg/ha) (BY)	0.55	0.46	-0.35		**0.69***	**0.57**	**0.78****
Grain yield (kg/ha) (GY)	0.47	0.38	-0.32	0.81**		**0.89****	**0.63***
Harvest index (%) (HI)	0.36	0.29	-0.24	0.60*	0.94**		**0.77****
100-seed weight (g) (SW)	0.51	0.39	-0.35	0.67*	0.70*	0.59*	

Values above the diagonal in bold are for irrigated conditions and below the diagonal are for rainfed conditions; ** and * indicate significance at 1 and 5% levels

food legumes opens more opportunity for marker-assisted improvement. This requires dissection of abiotic stresses into its components, availability of reliable mapping populations, and identification and validation of trait-associated markers across different environments and their pyramiding.

Several gene transfer approaches have been shown to improve the stress tolerance in crop plants. The transferred genes including those encoding for enzymes for modifying membrane lipids, LEA proteins, detoxification enzyme and stress-inducible transcription factors have been demonstrated to have great potential. Many genes have been shown to be induced by drought stress. The products of these genes are thought to function not only in stress tolerance but also in the regulation of gene expression of the stress-inducible genes and in signal transduction in the stress response. Two cDNA clones that encoded dehydration responsive element binding (DREB) proteins, DREB 1A and DREB 2A, have been isolated from *Arabidopsis*. Over-expression of the DREB 1A cDNA activates strong expression of the target stress-inducible genes under unstressed conditions, which in turn increases tolerance to drought stress. Efforts have also been made to insert *Cod A* gene from bacteria into chickpea, which is expected to enhance tolerance to drought.

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Community-based breeding programs to exploit genetic potential of adapted local sheep breeds in Ethiopia

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Abstract

Indigenous breeds are likely to cope better with climate change than exotic breeds, because they are already adapted to harsh conditions. Breeding programs will not be able to improve adaptation traits in exotic breeds fast enough to keep pace with climate change. The better alternative is to focus on improving production traits in adapted indigenous breeds. Designing breeding programs for adapted indigenous breeds owned mostly by small-scale farmers requires, among others, an understanding of the production system of the target area and the definition of breeding objectives in a truly participatory manner. We present here activities of a project on designing community-based sheep breeding strategies in four locations representing different agro-ecologies that are habitat to four indigenous sheep breeds (‘Afar’, ‘Bonga’, ‘Horro’ and ‘Menz’). The production systems were described using surveys and workshops. Breeding objective traits of sheep owners were identified by surveys, hypothetical choice experiments, and ranking of live animals in the farmers’ own flocks and of groups of animals penned in a central location. The application of various methods allowed a validity cross-check of results and ensured that all traits are captured. The production systems were characterized as pastoral system for Afar, mixed crop-livestock system for Horro and Bonga, and sheep-barley system for Menz. Mating system was predominantly uncontrolled. Early disposal of breeding stock, diseases and feed shortage (mainly in Afar and Menz) were identified as the major problems. Six traits for ewes (body size, coat color, mothering ability, twinning, lambing interval, tail type) and five traits for rams (body size, coat color, tail type, libido and presence or absence of horn) were identified as breeding objective traits of the smallholders, and one additional trait (milk yield) for Afar. This information was used in the simulation of alternative breeding strategies for the different communities and then discussed with the communities.

Keywords: breeding objectives; community based breeding; Ethiopia; production system; indigenous sheep breed.

1. Introduction

Small ruminants play an important role in the livelihoods of resource-poor households in Ethiopia. The current level of on-farm productivity of the indigenous Ethiopian sheep genetic resources in the smallholder production systems is low. Off-take rates are about 33% with 10 kg of carcass output (Tibbo 2006) and a net output of 3.7 kg meat per animal in a flock. In parallel, the demand for sheep products (mutton and sheep skins) has increased due to increased human population and urbanization. There is therefore, an urgent need to increase productivity to improve smallholder farm income and to meet the demand of the growing human population for livestock products.

While considering productivity improvement for market targeting, assessments of views of farmers, and research and development agencies in the highlands of Ethiopia showed that breeding issues receive similar priority as feeding issues (Tibbo 2000). Thus, there is a clear need to develop efficient means to facilitate the access by livestock keepers to improved germplasm.

Transfer of proven genetic improvement approaches from developed to developing countries has been unsuccessful. Centralized breeding schemes, entirely managed and controlled by governments with minimal participation of farmers were developed as an alternative and implemented in many developing countries. These were done through a nucleus breeding unit limited to a central station, usually run by a governmental organization. These plans were entirely managed and developed without the active involvement of the community who played a passive role in the collection of information or allowing government staff to collect data on the basis of a contractual agreement. Thus, the schemes failed to provide improved males continuously and also failed to engage the participation of the end users in the process.

Another alternative widely followed by many countries or individuals was the import of European germplasm via live animals, semen or embryos, in most cases without having previously tested the suitability and adaptability of these breeds and their crosses in the target areas. This approach is questionable if the adaptation of these animals to the harsh conditions they will be placed in is not assessed. Also, indiscriminate crossbreeding with the local populations tends to genetically erode the adapted local population. The use of exotic breeds and possibly their crosses could also be questioned in light of climate change. Indigenous breeds are likely to cope better with climate change than exotic breeds, because they are already adapted to harsh conditions. Breeding programs will not be able to improve adaptation traits in exotic breeds fast enough to keep pace with climate change, and the better alternative is to focus on improving production traits in the indigenous breeds. A new approach is, therefore, required.

One approach that has recently stimulated global interest is a community-based breeding strategy. It takes into account, from the very start, farmers' decisions and enlists their participation that determines success. Proper consideration of farmers' breeding objectives, infrastructure, participation and ownership is made (Sölkner et al. 1998). Designing a community-based breeding program goes much beyond genetic theories and increased productivity. Matters of infrastructure, community development and an opportunity for improved livelihood of livestock owners through better animals and markets for their products are integral to this strategy. Designing breeding programs for indigenous breeds, owned mostly by small-scale farmers, requires, among others, an understanding of the production system of the target area and the definition of breeding objectives in a truly participatory manner. This paper reports on production systems and breeding goals of four communities where ICARDA-ILRI-BOKU project is designing community based sheep breeding programs for Ethiopia.

2. Methodological framework

2.1. Study sites and breeds

The International Centre for Agricultural Research in the Dry Areas (ICARDA), in partnership with the International Livestock Research Institute (ILRI), University of Natural Resource and Applied Sciences (BOKU), Austria, and the Agricultural Research Systems in Ethiopia, is designing community-based sheep breeding strategies in four locations in Ethiopia, representing different agro-ecologies that are habitat to four indigenous sheep breeds - 'Afar', 'Bonga', 'Horro' and 'Menz' (Figure 1).

Menz is located in the Ethiopian highlands at about 300 km north-east of Addis Ababa with an altitude range of 2700 to 3300 m.a.s.l. Menz area is considered as the epicentre of distribution of the Menz breed. The Menz breed is one of the few coarse woolly fat-tailed sheep types, adapted to high altitude precipitous terrain with scarcity of feed and where production of crop is limited due to extreme low temperature and drought in the cool highlands. This is a hardy small breed which controls level of internal parasites infection and is productive under low input production circumstances of the degraded ecosystems (Getachew 2008).

Horro is located in the western Ethiopian mid-highland region (i.e. 1600 to 2800m altitude) at about 310km from the capital, Addis Ababa. Horro is believed to be closer to the epicentre of the Horro sheep breed, origin. The breed has been well described earlier (Galal 1983). Briefly Horro sheep is a fat-tailed hair-type sheep with bigger growth potential compared with other indigenous breeds in Ethiopia. Farming in the Horro area is dominated by mixed crop-livestock system.

Bonga is located in south Western part of Ethiopia at about 460 km from Addis Ababa, with altitude ranging from 1000 to 3400 meters. The temperature in the area can be as high as 24 ºC and can also reach lowest value of 12 ºC (Denboba 2005). For Bonga breed the tail is wide and long. Both male and female are polled; the ear is long, the hair is short and smooth. The breed is judged as good for traits like growth rate, meat quality, fattening potential, twining rate and temperament (Edea 2008). The prominent farming system is a mixed crop-livestock production.

Werer is a small town in the dry areas within the Rift Valley region in Ethiopia located 250km from Addis Ababa. It is located in the Afar regional state, where pastoralism is a way of life. Afar breed is fat-tailed but with a very different shape (shield shaped and descends to the hocks, with short S-shaped upturned tip) with no wool. The Afar sheep is a hardy breed adapted to drought prone arid and semi-arid areas of the middle Awash valley of eastern Ethiopia which includes the coastal strip of the Danakil depression and the associated Rift Valley in Ethiopia, with the Afar nomadic pastoralist (DAGRIS 2006; Getachew 2008).

2.2. Methodology

To describe the production system relevant information was collected through interviews conducted with randomly selected livestock keepers from the study sites. A total of 457 households (108 from Afar, 114 from Bonga, 115 from Horro and 120 from Menz) were interviewed. The questionnaire was carefully designed, pre-tested and modified before the commencement of the actual administration to check its clarity to respondents and appropriateness of the questions. General information list of FAO (2000) and Oromia livestock breed survey questionnaire (Ayalew et al. 2004) were used as checklist in designing the questionnaire.

For phenotypic ranking of groups of live animals, fifteen ewes and 15 rams were randomly selected from the communities' flocks at each study site, marked and randomly assigned into five subgroups held in a pen. A total of 30 sheep owners from each site were moved to the other site (each location has two sites) for the phenotypic ranking of animals. Each interviewee was asked by an enumerator to rank the animals within each pen according to his/her own preferences and give the reasons for their ranking animals as 1st, 2nd and 3rd. They were then made aware of the life history of the animals and asked if they would like to change their ranking.

The sheep owners were also asked to rank the ewes as 1^{st}, 2^{nd}, 3^{rd} and worst and to provide reasons for their ranking. After having detailed information from the owners, linear body measurements including body length, chest girth,

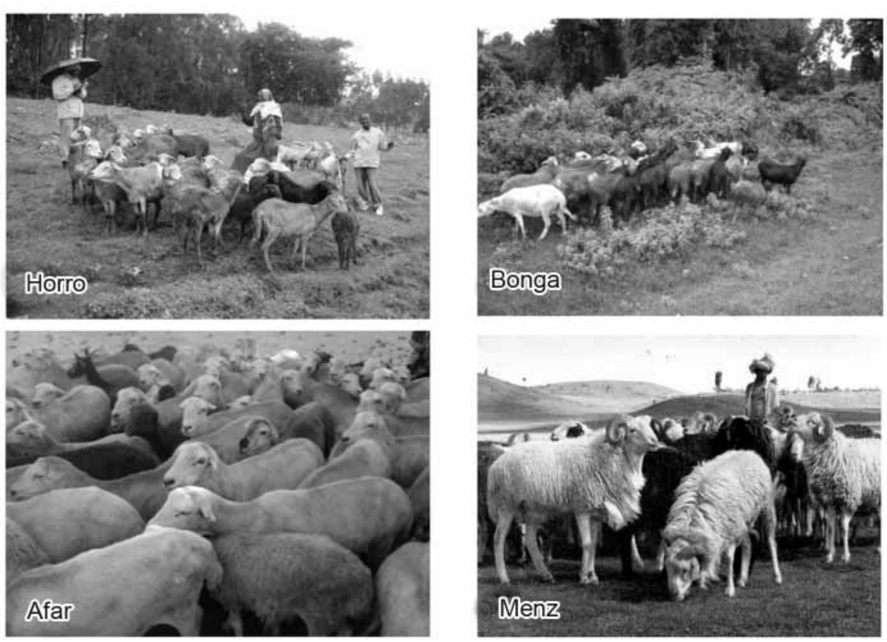

Figure 1. The four sheep breeds for which community based breeding program is being designed.

heart girth, ramp circumference, ramp height, tail length, tail circumference, body condition, ear length, dentition and pelvic width were taken on each individual animal ranked as 1st to 3rd and worst. This was firstly to investigate whether the ranking made by farmers goes with the actual measurements taken on animals and secondly to get better understanding about the animals.

To design the choice experiments, information about farmers' preferences of different traits was gathered from the survey results. Respondents were presented with a series of choice sets, each containing five or six alternative traits: six traits for ewes (body size, coat color, mothering ability, lambing interval, twining rate and tail type) and five traits for rams (body size, coat color, tail type, libido and presence or absence of horn) except for the ewes of one sheep breed where one additional trait (milk yield) was used. From each choice set, the respondents were asked to choose their preferred alternative. The attributes used were common across all alternatives. Each of the traits was grouped into two classes "good" or "bad". There was also an option for not choosing any of them. The trait categories were described to interviewees using drawings of hypothetical types of sheep. For those traits that could not be described using drawings, trade-offs between the different traits categories were described verbally.

Data were analyzed using SAS software (SAS 2002).

3. Results and discussion

3.1. Description of the production systems

The production systems were characterized as pastoral system for Afar, mixed crop-livestock system for Horro and Bonga, and sheep-barley system for Menz (Table 1). In Menz, high altitude, precipitous terrain, recurrent drought, cold temperature and windy climate have limited the agricultural production to 'sheep-barely' or just 'sheep' production system. The sheep in the Menz area are thus perceived to be the hardiest sheep types evolved under stressful environments.

Horro and Bonga areas are characterized by wet humid climate where mixed 'crop-livestock' system is practiced. Horro and Bonga sheep are kept in small flocks, along with other livestock species (cattle, goats and equines) in communal grazing areas, unsuitable for cropping, or on fallow and waterlogged lands.

The Afar sheep are located in arid and semi-arid lowland areas. Livestock is the mainstay of the people here. Other important species in this system include cattle, goats and camels. Constant or partial herd mobility is a strategy used here to achieve feed and water.

3.2. Reasons for keeping sheep

The primary reasons for keeping sheep in Bonga, Horro and Menz were to generate income, and as a source of meat and manure. None of the respondents kept sheep for milk production, which is associated with cultural taboo against the use of sheep milk for consumption. For Afar pastoralists, the primary reason for keeping sheep was for milk production followed by meat and income generation. The results indicated the relative importance of tangible benefits of sheep keeping (such as regular source of income, meat, and manure). Functions like for ceremonial purposes received relatively low ranking among the reasons. Similar multi-purpose functions of sheep rearing

Table 1. Characteristics of the four sites.

Breed	Habitat (elevation)	Production system	Major use
Afar	Hot to warm arid plains (565-1542 m a.s.l)	Pastoral/agro-pastoral	Milk, meat
Bonga	Wet, humid (1070 -3323 m a.s.l)	Mixed crop-livestock	meat
Horro	Wet, humid (1600-2800 m a.s.l)	Mixed crop-livestock	meat
Menz	Tepid, cool highland (1466-3563 m a.s.l)	Sheep-barley	Meat, wool

were reported from the central highlands of Ethiopia (Mekoya 1999). Multiple values of indigenous livestock breeds in the developing countries are particularly important in low and medium input production environments (Mwacharo and Drucker 2005; Wurzinger et al. 2006). Lack of proper recognition of the purpose of keeping animals by their owners has been a major reason in the failure of past genetic improvement programs (Sölkner et al. 1998). Therefore, knowing the purpose for which sheep are kept would help in designing strategy for sustainable improvement.

3.3. Herd size and flock structure

Average flock size in Afar, Bonga, Horro and Menz was 23.0, 11.3, 8.2 and 31.6 heads, respectively. Small flock size was identified as one of the limiting factors in applying within-breed selection at the household level. Consequently, households with small flock size did sell their best (fast-growing) breeding animals inadvertently primarily due to shortage of cash. This results in negative selection since mediocre rams will be allowed to mate in such flocks. Therefore, a selection scheme applicable to the whole village level, to reverse this trend and improve flock productivity, is needed, which is the main objective of this project.

Ewes account for about 67.3, 60, 80 and 61.2% of the total flock in the Afar, Bonga, Horro and Menz areas, respectively. Mukasa-Mugerwa (1986) also reported only 52.5% ewes in the thin-tailed Ethiopian sheep. Abegaz (2007), working on Gumuz sheep, reported that only 42.6% of the flock was composed of adult females. Wilson (1986) noted that the higher proportion of males in the traditional systems was an indicator that the objective of sheep owners was to have cash income or meat production.

3.4. Breeding practices

Breeding was generally uncontrolled in Bonga, Horro and Menz. The majority of the Afar sheep owners, however, reported that they try to avoid dry season lambing (86%) and indiscriminate mating (11%). Methods like ram isolation, castration and tying of a cord around the neck of the scrotum and looped over the prepuce to prevent extrusion of the penis of the ram were used to control mating in Afar. Maasai tribe in Kenya uses 'olor' as condoms to prevent mating (http://news.bbc.co.uk/2/hi/africa/7648860.stm).

Many owners keep their own breeding ram. When breeding males are not reared in their flocks, service from neighbors' rams or those in communal grazing areas is obtained, leading to random mating. It was learnt that sheep keepers alike select breeding rams at the age of six months. They are however kept in the flock until one year when they fully start service. The rams are used for two years before they are fattened and sold in Bonga, Horro and Menz; where as in Afar they are used for at least three years.

Table 2. Ranking of sheep production constraints by sheep owners

Constraints	Afar	Bonga	Horro	Menz
Feed shortage	0.55*	0.135	0.307	0.37
Disease	0.33	0.367	0.470	0.35
Market	0.00	0.018	0.017	0.02
Predator	0.02	0.219	0.094	0.01
Labor shortage	0.00	0.237	0.032	0.02
Genotype	0.01	0	0.025	0.08
Drought	0	0	0.037	0
Lack of education	0	0	0.002	0
Water	0.07	0	0.008	0.01
Theft	0	0.005	0.004	0
Capital	0.01	0.015	0	0.15

*Index values computed as sum of scores (3 for rank 1 + 2 for rank 2 + 1 for rank 3) for a particular constraint divided by sum of scores (3 for rank 1 + 2 for rank 2 + 1 for rank 3) for all constraints

3.5. Constraints to sheep production

In all the production systems diseases represent a major constraint to sheep production (Table 2). Except for Bonga area, feed shortage/frequent drought was also considered as an important problem. Other constraints with varying level of importance were also identified, including the shortage of capital to start or expand sheep production and lack of improved genotype in Menz, water shortage in Afar, presence of predators in Horro and Bonga, and labor shortage in Bonga.

Weakening of traditional management of communal grazing lands, overgrazing, encroachment of cropping into the grazing land, and human population growth were the main factors for declining and shrinkage of the primarily grazing land, the main feed source, especially in Horro district. Poor veterinary services and absence of transportation facilities were also identified as limiting factors. The swampy nature of communal grazing areas in Horro district associated with high incidence of internal parasites such as liver fluke also influenced sheep production.

3.6. Breeding goal traits

The results of individual interviews and discussions indicated that the majority of the farmers (90%) and pastoralists (80%) recognize the importance of selection and they practice selection with their own criteria. Although there are commonalities in the traits selected in different sites, the order of importance varies.

It was found that traits like body size, appearance and/or conformation, coat color, libido and tail formation were considered important in all the sites and given due emphasis in selecting breeding rams. Body size, coat color and tail formation (size and shape) were equally important for ewes. Additionally, milk yield (for Afar), lambing interval, mothering ability, age at first lambing and twining rate (particularly for Bonga and Horro) were also considered in selecting breeding females. Adaptive traits such as tolerance to diseases and feed shortage were given low emphasis in selecting replacement stocks in both areas.

As was indicted before, the traits with better ranks identified during the survey were used to design choice cards. Hypothetical choice and phenotypic ranking (both in own flock and of animals selected from others' flock) experiments were conducted in the field to confirm the trait preference of owners obtained during the survey. Six traits for ewes (body size, coat color, mothering ability, twinning, lambing interval, tail type) and five traits for rams (body size, coat color, tail type, libido and presence or absence of horn) were identified as breeding objective traits of the smallholders, and one additional trait (milk yield) for Afar. Measurable traits confirmed to be important during the whole exercise were used to simulate alternative breeding plans. Traits with qualitative nature (e.g. coat color, horn type, etc.) but considered important were not included in the simulation of the breeding plans - animals that do not posses such traits will be culled using the independent culling level method in order to accommodate farmers' preferences.

The different methods of defining breeding objective traits have advantages and shortfalls. One has to analyse the practical situation on the ground before deciding on the method to be used. However, Wurzinger et al. (2008b), who compared three different methods (survey, phenotypic ranking of live animals and a hypothetical choice experiment), suggested a combination of at least two methods in order to avoid overlooking any important question for selection. It was reported that these methods are applicable for situations where farmers have low levels of literacy and/or only a few years of formal education (Ndumu et al. 2008).

3.7. Implications for poverty alleviation and adaptation to climate change

Sheep production in Ethiopia is based on adapted indigenous breeds; exotic sheep (mainly Awassi-Menz crossbreds) constitute less than 1 % in specific areas (Menz, South Wollo). Improvement strategies designed on indigenous sheep will therefore result in access to more protein and incomes to smallholders and ensure sustainability of their livelihoods. Farmers' capacity to undertake participatory breeding will bring self-confidence in the future to accomplish community-based research for development programs.

Climate change affects livestock and thus livelihoods in many ways. Although long term impacts are difficult to predict and are bound to vary from one location to another, most climate change reports (IPCC 2007; Mengistu 2008) indicate rising temperatures and decreasing rainfall in many areas. As a result, these areas will tend to become drier, and existing water shortages will worsen. In addition, climate change is likely to bring about even more erratic and unpredictable rainfall and more extreme weather conditions such as longer and more frequent droughts. In pastoral areas, the effects of these events are going to be severe. In many areas, the rangeland is degraded and changed into bare fields dotted with termite mounds (Figure 2). The encroachment of unpalatable bushes is increasing. In the future, domesticated animals may be increasingly exposed and susceptible to 'new' and re-emerging diseases, such as Rift Valley fever, the incidence of which is altered by changes in temperature and rainfall patterns. When this happens, the delicate balance in the production systems would be undermined.

The implication of the above is that the environment won't be able to support exotic breeds. The focus should therefore be on locally adapted indigenous breeds, which are likely to cope better with climate change than exotic breeds, because they are already adapted to harsh conditions (Tibbo et al. 2008). Mechanisms designed to adapt to climate change should aim to increase household food security and household income. Breeding programs will not be able to improve adaptation traits in exotic breeds fast enough to keep pace with climate change. The alternative is thus to focus on improving production traits in indigenous breeds.

Figure 2. Highly degraded rangeland in Moyalle, Ethiopia.

4. Conclusion

Breeding strategies targeted at genetic improvement of sheep breeds need to incorporate the multi-functional roles that sheep play in these systems and focus on those traits identified as important by the sheep owners. Sustainable strategy needs to be tailored to the specific goals of the targeted communities and production systems/ environments as no single strategy fits all situations. Early disposal of breeding males, small flock sizes, uncontrolled mating, and absence of structured breeding program makes genetic improvement difficult. The health and feed situation also needs to be rectified if any meaningful impact is expected. Community based breeding would help in bringing farmers/ pastoralists around the same goal to help them agree to and act collectively on designing mechanisms that ensure sustainable genetic improvement. Farmers' indigenous knowledge and experiences on sheep breeding practices should be an integral part of the strategies. Concentrating on indigenous breeds would also help the owners to adapt to climate change.

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New feeding strategies for Awassi sheep in drought affected areas and their effect on product quality

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Abstract

The rangelands of Middle Eastern countries are already severely degraded due to overgrazing and frequent droughts. As a consequence, livestock farmers face high and increasing feeding costs, particularly during the milk production period. It is predicted that climate change will worsen this situation due to increasing temperature, less rainfall and an even higher frequency of droughts. This study aims at counterbalancing this trend by using cheaper unconventional ingredients in balanced diets. The use of cost optimized supplemental diets was tested with 42 Awassi ewes at the International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria. The sheep were grazed daily on marginal rangelands for six hours. Milk production and dairy products obtained with the conventional supplementary feed used by farmers was contrasted with production under 5 cost-optimized nutrient balanced diets. In one of the treatments (T5) sheep grazed on vetch instead of rangeland and the supplementary feeding was adjusted accordingly. While the traditional supplementary feed was based on barley grain, wheat bran and barley straw, the improved diets included other locally available feeds like cotton seed cake, molasses, sugar beet pulp, and ammoniated wheat straw. The average daily milk production of Awassi ewes in 4 out of the 5 tested diets was at least 25% higher than that in the control diet. Texture profile analysis (TPA) of the milk products showed a positive effect of alternative diets on cheese hardness and yogurt firmness. In 4 out of 5 alternative tested diets, cheese hardness increased at least 9% and yogurt firmness at least 4% over the control group. As these are important characteristics used for pricing yogurt and cheese in the Middle East, the four diets show a good potential to increase profits for the producers. The sensory data analysis of cheese revealed that texture was improved in 4 out of 5 alternative tested diets, whereas the chewiness was improved only in 3 diets over the control. The measured sensory traits of yogurt were improved in 4 out of 5 alternative tested diets over the control diet. The alternative diets containing agro-byproducts and ammoniated wheat straw are apparently options for resource-poor farmers in the Middle Eastern region to increase their productivity and income without affecting the main quality of their milk products.

Keywords: agro-byproducts, Awassi sheep, diet supplementation, feeding strategy, Middle East, milk yield, texture profile analysis of yogurt.

1. Introduction

Sheep production plays an important role in supporting the livelihood of resource-poor farmers in the low rainfall regions of West Asia. These regions are severely affected by droughts (ICARDA 2000). The capacity of Awassi sheep to transform often unused vegetation, good adaptability to the rather harsh environmental conditions (Wachholz 1996) and ability to produce highly demanded products in the markets make them a suitable choice for income generation and in meeting the nutritional needs of the family. This multipurpose breed, indigenous to West Asia, is one of the most remarkable breeds in this context (Epstein 1985).

The rapid increase in human population is leading to important changes in the market scenarios for agricultural products in the Middle East. This increase is associated with an expansion of markets and a raising demand for high quality animal products, particularly milk products and meat produced by sheep. This offers promising opportunities for farmers to enhance their income and improve their livelihoods in the dry areas (ICARDA 2003). Cheese and yogurt, widely consumed directly or as a component of the local cuisine, are among the highly demanded products that dairy sheep farmers of the Middle East region are producing to benefit from these market opportunities. It is estimated that most of this product is produced by resource-poor farmers. It also provides the farmers with essential source of protein, especially to the children.

This trend of increasing demand for sheep products unfortunately goes in parallel with a decline in the contribution of rangelands to animal diets because of drought and increasing overgrazing. The reduction in the carrying capacity of the rangelands has imposed a serious constraint on the livestock production systems. To target the market prospects for traditional products, farmers are resorting to intensify their production systems by purchasing feeds, whenever needed, to compensate for the lack of fodder in the range. High feeding costs represent the most serious limiting factor for farmers to target markets (Hartwell et al. 2008).

Globally, climate change and the diversion of food and feed cereals for bio-fuel production are responsible for at least 30% of the hike in the global feed prices (Leng 2009). It is expected that in the coming 30 years, the production of bio-fuel alone will limit the feed grain resources by 24%, affect the food grain resources by 10% and increase the risk of human hunger by 15% (Fischer et al. 2009). Climate change will adversely impact the livestock farmers by enhancing heat stress to the animals, and accentuating the scarcity of water and fodder (ICARDA 2008).

In addressing those problems, ICARDA has successfully developed strategies to reduce feeding costs for lamb fattening systems utilizing some of the low-cost feedstuffs available in the region (Rihawi et al. 2008). However, the use of these agro by-products has not been assessed for their effect on the quality of dairy products in the region. Feed and feed composition affect not only the yield and composition of milk but also the quantity and quality of the products such as cheese (Bencini 2001) and yogurt (Salvador and Fiszman 2004), thereby affecting the price of the products. Sensory attributes are important factors for consumer and product marketing (Park and Drake 2005). Based on these considerations, this study assesses the influence of changes in the feeding system - in response to decreasing ability of rangelands to contribute to the animal diet and high feed costs- by using alternative feed diets, on the quality of milk and main milk products to offer options for farmers to cope with the situation. The focus is on changes in the characteristics of the milk products that affect product price in the market.

2. Material and methods

2.1. Animal and diets

A rapid survey on dairy sheep farms was conducted in Aleppo province to assess feeding diet used by farmers during the milk production period to use that as the ‘control’ diet in this study. The control diet and five other alternatives (‘test’ diets) were formulated and tested on 8 Awassi lactating ewes at ICARDA’s sheep unit at Tel Hadya, near Aleppo, Syria. The test diets consisted of conventional feeds such as barley grain, wheat bran, as well as unconventional items such as cotton seed cake and low cost feeds such as ammoniated wheat straw, molasses and sugar beet pulp. Animals in all the test diet treatments were allowed to graze as a basal diet so that all test diets had the same level of crude protein and energy, while the control diet was set to be ‘average’ diet used by dairy sheep farmers. All animals grazed on range except those under the test diet 5 that instead grazed on vetch (Table 1).

The diet was composed, according to the requirements of milking animals (MAFF 1987), as shown in Table 1; the requirement was covered by the pasture and supplemented diet. The design was such that each animal received daily 229 g of crude protein and 18 MJ of metabolizable energy (ME). Under the traditional feeding regime (control), ewes received less protein but similar level of energy as those under the test diets. In the group of test diet 5, which involved vetch grazing, the feed supplement provided 72 g of crude protein and 9.8 MJ of energy while vetch provided the remaining amount of crude protein and energy. Bulk milk was collected once every two weeks for the animals in each test group.

2.2. Processing of milk products

Cheese: Farmers and small scale cheese makers in the region produce white fresh cheese. In this study milk was batch pasteurized after filtration

Table 1. Composition and nutritive value of the control diet and the alternative test diets.

	Treatments[1]					
Items in diet	**TD 1**	**TD 2**	**TD 3**	**TD 4**	**TD 5**	**CD**
Ingredients						
Barley	+	+	+	+	-	+
Sugar beet pulp	-	+	-	+	+	-
Molasses	-	+	-	+	+	-
Cotton seed cake	+	+	+	+	-	-
Wheat bran	+	-	+	-	+	+
Urea-treated wheat straw	-	+	+	-	-	-
Barley straw	+	-	+	+	+	+
Pasture						
Range	+	+	+	+	-	+
Vetch	-	-	-	-	+	-
Intake and composition of supplements						
DMI (kg/d)	1.2	1.2	1.2	1.2	1.3	1.2
CP (% of DM)	12.3	12.6	13.0	12.5	5.6	8.4
ME (MJ/kg of DM)	8.7	9.2	9.8	9.4	7.7	9.1
CP:ME	14.1	13.8	13.3	13.4	7.3	9.3

[1]CD = control diet; TD 1 to 5 = test diet 1 to 5.
+ denotes application of the particular feed ingredients and pasture type

at 73°C for 15 sec then cooled to 40°C. Cheese culture (R703, Chr-Hansen, Hørsholm, Denmark), which included *Lactococcus lactis* ssp. *lactis* and *Lactococcus lactis* ssp *cremoris*, was used. A stock culture was prepared using autoclaved milk. Stock culture was added to the milk at an amount of 0.1 ml/L along with 0.1 g/L of $CaCl_2$. Clotting enzyme (CHY-MAX®, Chr-Hansen, Hørsholm, Denmark) was added after 15 min at the amount of 1.5 g/100 L. The curd was cut into 1 cm^3 cubes 1 h after the addition of clotting enzyme. Before stirring, the curd was allowed to settle for 15 minutes and then gently agitated for 15 min to avoid fusion of freshly cut curd and facilitate whey separation. The curd was transferred into cheese cloth and molded in 20×20×10 cm molds and pressed for 10 h. The curd was placed in 12% pasteurized brine for 4 h in a cool room (8°C). The milk from different diet treatments was processed into cheese simultaneously using a laboratory dairy processing unit consisting of 8×5 L stainless steel containers.

Yogurt: Farmers in the region produce a set-type of yogurt (locally called Laban or Khather) in 3 to 5 L buckets. For this reason, set-type yogurt was prepared using a yogurt culture (YC 180, Chr-Hansen, Hørsholm, Denmark), which included *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* and subsp *lactis*. A stock culture was prepared using autoclaved milk. Fresh milk from the sheep of different diet groups was heated at 85°C for 30 min, and at a temperature of 43°C it was inoculated with 3 % of stock culture. Inoculated milk was incubated at 43°C for 4 hours then cooled down to 8°C.

2.3. Chemical analysis

Bulk milk was collected once every two weeks for each diet group. The content of total solids, fat, protein and lactose was determined using a Milkoscan 133B device (Foss Electric, Hillerød, Denmark). Titratable acidity of yogurt was measured according to IDF standard 150 (IDF 1991). The results were expressed as percentage of lactic acid. Moisture of cheese was determined by drying in forced air oven at 105°C till constant weight. Cheese fat was determined using Gerber method, and the content of protein in cheese was determined by the Kjeldahl method (AOAC 2000).

2.4. Texture measurements

Texture measurements of cheese and yogurt were performed using texture analyzer (TA-XT2, Stable Micro Systems Ltd., Surrey, UK). A 20 mm diameter cylindrical probe was used to penetrate yogurt samples prepared in 50 mL glass beakers. The penetration was done to 20 mm with a speed of 1 mm/s. Cheese samples were analyzed using a 6 mm diameter cylindrical probe. The penetration of cheese samples was done to 10 mm with a speed of 1 mm/s in two consecutive compression modes. Samples were analyzed in triplicate. The results were plotted in force-time graphs, where maximum force represents the firmness of yogurt and the hardness in cheese. In addition to cohesiveness, gumminess of cheese was calculated using Texture Expert software V1.22 provided with the device according to Tunick (2000).

2.5. Sensory evaluation

Sensory parameters that affect price of cheese and yogurt were assessed based on a quantitative descriptive ranking method with 5 point scale (1 = worst, 5 = best), higher values indicate stronger attributes (Carpenter et al. 2000); the scale was used to score four separate quality traits. The cheese sensory traits were chewiness, smell, taste and texture and the yogurt sensory traits were appearance, smell, taste and texture. The assessment was done by 10 consumers (local employees at ICARDA). The consumer panel was trained to evaluate cheese and yogurt samples using the score ranking method. Samples were evaluated at a temperature of 10°C.

2.6. Statistical analysis

The effects of diet treatments on chemical composition of milk and physical properties of cheese and yogurt were analyzed by linear models using GLM-SAS procedures. Sensory data was analyzed using GENMOD-SAS procedures linking to a cumulative logits (SAS software, V9.1).

3. Results and discussion

3.1. Milk and milk composition

The data on daily milk production and the milk composition are shown in Table 2. The tested diets affected the daily milk production ($P < 0.01$). The production increased from 25.30 to 38.14% over the control in the test diets 1 to 4, showing that these diets are good alternative to the traditional diets in dry areas, whereas diet 5 reduced the daily milk production by 14.76% as compared to the control diet. The increase in daily milk production could be attributed to the use of the nutritionally balanced diets as was also reported by Carnicella et al. (2008) in case of the Maltese goats with a control diet of starchy feed like the control diet in our study.

Traditional diets used by farmers in the region, based on expensive barley grain and rich in energy, had a negative effect on milk yield in ewes, which were in the middle of their lactation period (Cannas et al. 2003), because they generally have a CP:ME ratio lower than 10 , which does not meet the requirement of lactating ewes. Deficiency of protein in traditional diets in West Asia has been reported by Al-Jassim et al. (1999) and lately

Table 2. Daily milk production and milk composition by the different diet treatments.

	Milk production(kg)	**Milk components (%)**			
Treatment[1]		**TS**	**Fat**	**Protein**	**Lactose**
TD1	1.068^{a}	17.63^{a}	6.51^{a}	5.46^{a}	4.96^{a}
TD2	1.107^{ab}	18.51^{b}	7.17^{b}	5.66^{b}	4.99^{a}
TD3	1.171^{b}	18.20^{bc}	7.14^{bc}	5.49^{ac}	4.88^{b}
TD4	1.063^{a}	18.30^{bd}	6.71^{ac}	5.87^{d}	5.02^{a}
TD5	0.723^{c}	17.91^{acd}	6.58^{a}	5.61^{bc}	4.77^{c}
CD	0.848^{d}	17.64^{ac}	6.48^{a}	5.66^{b}	4.80^{c}
SEM	*0.027*	*0.20*	*0.15*	*0.05*	*0.03*

[a-d] Values within a column with different superscripts differ $P < 0.05$ probability.
[1]CD = control diet; TD 1 to 5 = test diet 1 to 5; TS = total solids

by Nefzaoui et al. (2008). Protein deficiency has been shown to lead to a considerable drop in milk production (Cowan et al. 1981).

Feeding the animals with diet 5, which contains the highest level of molasses (35%), caused a reduction in daily milk production. This could be due to the effect of high level of soluble sugars. High soluble sugar diets accelerate rumen fermentation that strongly reduces rumen pH and leads on one hand to reduction in the fiber digestion (Martin Jr. and Wing 1966; Murphy and O'Mara 1993; Van Soest 1994) and on the other to an increase in propionic acid. The latter is mainly utilized for the biosynthesis of glucose and leads to the deposition of fat in the body tissues. Also, high quantities of molasses in the diet could lead to protein depression (Owen et al. 1971) and thus cause reduction in milk yield (Preston 1988). As indicated earlier, diets 1 to 4 performed better in terms of seasonal total milk production, than the control diet. This will have a positive impact on the economic returns to the farmers (Hilali et al. 2008).

The fat, protein and lactose concentration of milk was significantly affected by the diet treatments ($P < 0.01$). Total solids increased under all the test diets, from 0.9 to 4%, over the control diet ($P < 0.05$). The fat content showed a remarkable increase in diets 2 and 3 that included urea treated straw. Urea probably enhanced the digestibility of wheat straw (Habib et al. 1998). Nurfeta et al. (2009) reported an increase of 3.3% in NDF and 1.3% in ADF in wheat straw treated with urea. Fiber content affects the rumination and the content of milk fat (Lu et al. 2005). The milk protein content was slightly lower under the test diet 1 and 3 compared to the control. The milk lactose content was significantly lower under the control diet and test diet 5 as compared to other diets. Henno et al. (2008) attributed the reduction in the lactose content in the milk to unbalanced diet, in particular to the deficit in protein that resulted in the low feed protein utilization in cows.

The materials used in formulating the test diets have been used in the region to varied degrees and each material has its own influence in affecting the overall digestibility of the diet and its nutritional balance. Molasses, although available at low price, have not been tried widely in the region in feeding dairy sheep. Use of cotton seed cake is common for feeding animals for fattening in the region but not for dairy ewes. Wheat straw is widely available at low prices and its digestibility and protein content can be improved by treating it with urea (Habib et al. 1998). Sugar beet pulp is an agro-industry byproduct available in the region; for example, approximately 13 million tons of raw sugar beet were produced in 2007 in the Middle East region (FAO 2009). The pulp has the ability to increase the milk yield and its fat content because of high content of digestible fiber. That is why the test diet 2 showed these improvements over the control diet. Cabiddu et al. (2006) observed similar effects in case of Sarda sheep, which were fed corn and beet pulp concentrates. Chewing the fibers in the diet stimulates rumination, which is important for regulating the rumen pH (Kellaway and Harrington 2004).

3.2. Cheese

The yield and chemical composition of the cheese are shown in Table 3. The diet treatments had a significant effect on cheese yield ($P < 0.05$) and some of its chemical constituents. The cheese yield tended to be higher under test diet 2 and 4 perhaps because of higher fat and protein levels in the milk under these diets (Jaeggi et al. 2004). The moisture and fat content of the cheese was affected significantly ($P < 0.01$) by the diet treatment but the protein content was not.

Cheese hardness is an important quality trait determining the cheese price in the market. The composition of the milk used for making cheese affects the cheese hardness (Lucey et al. 2003). The hardness in our study increased under the test diets 1 to 4 due to the increase in the macro-components of the milk (Table 2). The increased content of milk protein also contributes positively to water-binding capacity in the cheese (Romeih et al. 2002), which is clearly seen in the cheese from the milk produced under test diet 2.

The differences in cheese smell and cheese taste assessed by the consumer panel were not significant, but the texture and chewiness showed a minor improvement under test diets 2, 3 and 4 over the control diet (Figure 1). It is important to note that, as compared to the control diet, there was no adverse effect of test diets on these parameters, which are important for determining the price.

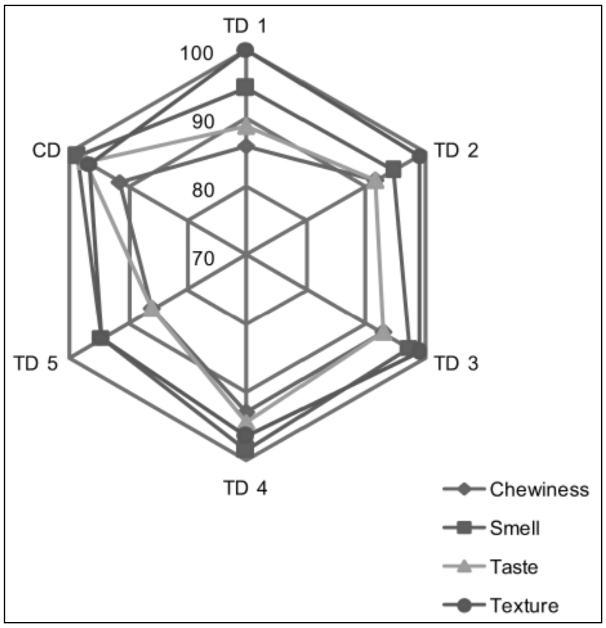

Figure 1. Effect of alternative test diets (TD) and the control diet (CD) on the cheese sensory properties (sum of the three highest scores).

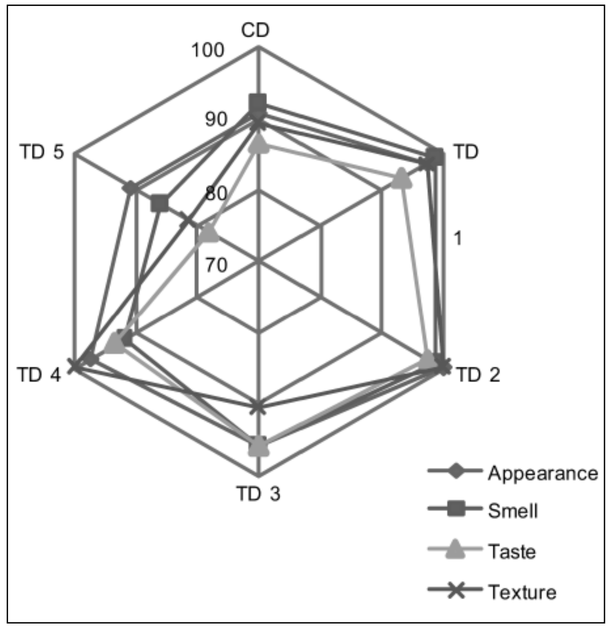

Figure 2. Effect of alternative test diets (TD) and the control diet (CD) on the yogurt sensory properties (sum of the three highest scores).

Table 3. Cheese yield and cheese composition.

Treatment[1]	Yield (%)	Moisture (%)	Fat (%)	Protein (%)	Hardness (g)
TD1	27.26[ab]	55.58[a]	24.70[a]	15.43	351.00a
TD2	27.49[ab]	57.03[b]	24.78[a]	15.38	317.52a
TD3	26.08[a]	53.74[c]	26.36[b]	15.32	281.66b
TD4	28.85[ab]	54.68[ac]	23.79[a]	15.33	243.98c
TD5	26.69[a]	54.47[c]	24.07[a]	14.90	220.10c
CD	27.22[ab]	54.62[ac]	22.38[c]	15.04	224.37c
SEM	*0.60*	*0.43*	*0.36*	*0.25*	*12.67*

[a-d] Values within a column with different superscripts differ P < 0.05 probability. [1]CD = control diet; TD 1 to 5 = test diet 1 to 5

3.3. Yogurt

Acidity and the physical variables measured in yogurt are shown in Table 4. Effects of diets on acidity were not significant ($P > 0.05$), because the same culture was used in all the cases. Middlemen in the region give the firmness of the yogurt as the first priority in fixing its price. In our study, the firmness increased under the test diets 1 to 4 over the control diet, the increase being particularly remarkable under the test diet 2 ($P < 0.01$). Under the test diet 5, however, there was a decrease as compared to the control diet. This could be attributed to the lower total solids and protein content of the milk under this diet. Nudda et al. (2005) also reported that yogurt firmness increased as the protein content of the milk increased. This is another beneficial effect of the test diets 1 to 4 for enhancing the income of the farmers.

Acidity and aroma in yogurt are developed by the culture. They are important components of the quality of the product (Omae et al. 2008) and they also affect the sensory properties of yogurt (Tamime 2006). The sensory variables assessed by the consumer panel were affected by the test diets ($P < 0.05$). The appearance, smell, taste and texture were enhanced by 6%, 4%, 7% and 9%, respectively, under the test diets 1 to 4 over the control diet (Figure 2). This is another potential benefit of these test diets for the resource-poor farmers.

Table 4. Effect of diets on the acidity and firmness of Awassi sheep milk yogurt.

Treatment1	Acidity (%)	Firmness (g)
TD1	1.49	36.31[a]
TD2	1.51	40.01[b]
TD3	1.49	36.06[a]
TD4	1.55	37.58[ab]
TD5	1.45	32.69[c]
CD	1.52	34.67[ac]
SEM	*0.05*	*1.12*

[a-d] Values within a column with different superscripts differ P < 0.05 probability. [1]CD = control diet; TD 1 to 5 = test diet 1 to 5; TS = total solids

4. Conclusion

The test diets 1 to 4 used in this study appear to provide a good option for resource-poor farmers to reduce the costs of feeding their dairy sheep while also improving generally the milk yield and quality of the traditional products they make and sell. Improved quality will increase the price these products can fetch in the market. Thus, the use of the selected diet alternatives can substantially enhance the income of sheep owners. Balanced feed, as presented by test diets 1 to 4, would prevent the wastage of energy offered to the animals by farmers in the traditional diet that is based on the use of costly barley or wheat grains, while reducing the feeding costs because the components used are locally available at affordable prices. The future marketability of cheese and yogurt in the region will be dictated by better quality standards to satisfy a population that has a tradition of consuming milk products (ICARDA 2001). Use of these diets for their dairy sheep by the resource-poor farmers will also permit adding value to the milk products and meeting the quality standards that will be increasingly demanded in the market in the future over what they currently achieve with their traditional feeding regime.

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Effect of grazing on range plant community characteristics of landscape depressions in arid ecosystems

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Abstract

Arid rangelands in Syria, referred to locally as the '*badia*', cover more than half of the country. These vast, dry landscapes are punctuated by broad dry basins ('*wadi*') or gentle landscape depressions that have relatively high productivity and are ecologically important as plant and wildlife habitat. This study examined the effect of two years of rest (no livestock grazing) on plant species composition, species diversity and vegetative productivity on paired landscape depressions in northwestern Syria. Average plant density was 31 and 868 plants/m^2 for grazed and protected depressions, respectively. Similarly, plant biomass was 467 and 2,299 kg DM/ha, respectively, for grazed and non-grazed sites. On continuously grazed sites, approximately 90% of the phytomass was of harmal peganum (*Peganum harmala* L.), a non-palatable, toxic perennial plant. The Shannon/Wiener diversity index was between 0.2 and 0.3 for the grazed areas, compared to 2 to 2.5 for the protected depressions. Thus, it is possible to increase the productivity and diversity of degraded landscape depressions in arid rangeland ecosystems. We suggest that rational, scientifically-based grazing systems that balance seasonal animal consumption with plant growth can maintain ecosystem services while providing forage for livestock.

Keywords: arid ecosystems, grazing, landscape depressions, rangelands, species diversity, Syrian *badia, wadi*

1. Introduction

Mankind is facing the negative repercussions of global climate change worldwide (Walker et al. 1999; IPCC 2000; WBGU 2000). A main consequence of the change in climate is an increasing shortage of natural resources, especially the freshwater resources, but also a serious threat to biodiversity (Cosgrove and Rijsberman 2000; Wolters et al. 2000; Thomas et al. 2004). Rangelands cover over one third of the Earth's land surface area and provide livelihoods for at least one billion people (UNCCD 2004). Moreover, they provide forage for livestock, habitat for wildlife, storage of carbon and water, source for renewable energy, and opportunities for such services as recreation and tourism (Nordblom and Shomo 1995). Rangelands, with their rich flora, also remain the primary source of genetic material for improving food crops and plant species for an increasing number of pharmaceuticals (White et al. 2000).

Rangelands in Syria, locally known as the '*badia*', cover more than 10 million ha, which is equivalent to about 55% of the country's land area (Al-Khatib 2008). In recent decades, however, major changes have occurred in the vegetation composition and diversity due to a combination of human-induced modifications, including overgrazing, excessive burning, fragmentation of areas, and decades of climatic stress (generally higher temperatures and lower annual precipitation). This is resulting in feed deficits and an expansion of desert margins (Le Houerou 1986; 1993; 1994; Salkini 2008). In particular, the impact of increased and excessive stocking rates during the last half century cannot be overstated. In fact, the number of sheep in the badia has increased from an estimated 3 million in 1950 to over 22 million in 2007 (MAAR 2008).

Given these circumstances, an understanding of vegetation dynamics of arid rangelands is an important prerequisite for understanding and predicting the responses of an ecosystem to disturbances such as overgrazing (Goldberg and Turner 1986). In degraded pastoral ecosystems, such knowledge can assist in restoring ecosystem integrity.

The need for rehabilitation of rangelands has particularly increased in the recent years with growing public awareness of, and concern over, the deterioration of range condition associated with overgrazing and the related threat to biodiversity (Call and Roundy 1991). Several studies have shown that overgrazing results in a compositional shift in plant communities (Noymeir et al. 1989; Westoby et al. 1989; Milton et al. 1994; Louhaichi et al. 2009). On degraded arid lands of western China, overgrazing not only altered the diversity of the palatable plants but also changed the morphological structure and distribution patterns of dominant species (Walker et al. 1999; Zhao et al. 2007). On the other hand, protection of vegetation against grazing in arid ecosystems has been suggested as a feasible approach to halting land degradation in order to rehabilitate rangelands (Heitschmidt and Taylor 1991). However, in certain cases the inability to revert degraded rangelands to former productive states by simply removing grazing pressure has necessitated the use of a more active approach to rangeland rehabilitation (Walker 1993; Westoby et al. 1989).

In non-tropical dry areas, broad *wadi* basins or gentle landscape depressions are considered as areas with great potential for sustaining vegetation (Wickens 1998). Historically, these depressions have served as important resources for providing livelihoods for the Bedouin communities. They provide forage late in the year – a period critical for livestock grazing, and they can yield good crop harvest, particularly barley. However, their productivity is increasingly under pressure due to overuse. In 1995, government policy in the Syrian steppe prohibited crop cultivation below the 200 mm rainfall isohyets, which would encompass most of the rangelands in the country (Ngaido et al. 2001). Nevertheless, strong quantitative and qualitative damage has already occurred to the natural vegetation. People living in the steppe that depend on these high-potential areas are under threat due to the declining productivity of these natural resources and the consequent instability of household incomes. In fact, many households perceive emigration to the cropping zone as their only long-term option for survival (Wachholtz 1996).

The present study aimed to assess the impact of grazing and the grazing exclusion effects on vegetation characteristics of two adjacent landscape depressions in the communal rangeland of Aleppo province, Syria.

2. Materials and methods

2.1. Study area

The study was conducted at Hazm Al Ser area communal rangeland situated within the Aleppo steppe (35˚37'78"N, 37˚32'96"E). The climate is Mediterranean arid, with winter rains showing high inter-annual variations and concentrated in the period from December through March. The climatic data of Mgherat, which is the nearest meteorological stations to the study area, indicates that the average annual precipitation is approximately 150 mm and mean monthly temperatures range from 2.4˚C in January to 39˚C in August, with an average annual temperature of 17.6˚C.

To quantify the differences between grazed and protected plant communities, two adjacent gentle landscape depression sites were randomly selected. Baseline data showed that in both sites *Noaea mucronata* is the dominant plant species along with dispersed annual plants. Soil is gypsiferous deposit in depressions and calcareous gypsic in undulating terrain. The first site that covered approximately 10 ha was subject to continuous grazing, while the second site of similar size was protected from grazing by the local community for two consecutive growing seasons (2007-2009). At each site, vegetation sampling was done and assessment made by species group, at the peak of the plant growth during the spring of 2009.

2.2. Vegetation sampling procedure

Identification of species: Samples of species were collected and tentative identification was done in the field. Unidentified or critical species were dried and compared to available identified specimens in the ICARDA Herbarium. Eco-characterization of plant taxa and plant nomenclature was based primarily on the work of Mutard (1966) and Zohary (1962).

Herbaceous cover: The line intercept method was used to determine herbaceous cover (Owensby 1973; Barabesi and Fattorini 1998; Bonham 1989). This is a rapid and accurate method for quantifying soil cover, including vegetation, litter, rocks and biotic crusts. These measurements are related to wind and water erosion, water infiltration and the ability of the site to resist and recover from degradation. For this method, a random starting point was established based on its orientation to the sampling area. From this point, three 50 m transect lines were established at 120° from each other. Observations at specified intervals (0.5 m) were recorded, and percentage cover was calculated as the proportion of the transect line covered by each species (Canfield 1941).

Plant density and herbaceous biomass: Plant density was expressed as the number of individuals of each taxon per surface unit (m^2). Six 1 m × 1 m quadrats were randomly placed to estimate plant density and biomass production. Above-ground biomass was harvested by manually clipping plants 2.5 cm above the soil surface within each quadrat. This height represents a typical standing crop height after the plants have been grazed by animals such as sheep. All plants were first identified and counted, then clipped and bagged. All vegetative material was oven dried (72 hr at 70°C), weighed, and the dry matter calculated. The percentage of total standing biomass for above-ground plant parts was determined for all species present.

Life form and palatability classes: The life form of the species was determined after Raunkiaer (1934). Plant species were split into eight groups based on morphology (life form) and life span. The groups included: chamaephytes (semi-shrub), phanerophytes (shrub), geophytes (perennial herb with bulb or tuber), therophytes (annual grasses), perennial grasses, biennial forbs, perennial forbs, and therophytes (annual forb). Using the data from the line intercept method, all recorded species were placed into three palatability classes, class I, II, and III representing species of high, moderate, and low palatability, respectively.

Similarity index and Shannon diversity index: Motyka's similarity index (Mueller-Dombois and Ellenberg 1974) has been widely used for quantitative evaluation of similarity and overlap of plant communities. The general formula is (%) = 2c/(a+b) x 100%; where c is the number of species common to both samples, a and b are the number of all species in sample A, and all species in sample B, respectively. Furthermore, the Shannon-Wiener diversity index (Weaver and Shannon 1949), given by the equation $H' = -\Sigma pI.\ln(pi)$, was used where pi is the proportion of species, I expressed as a proportion of the total number of individuals of all species, ln is the natural logarithm, and Σ represents the total pI. The ln (pi) for all species was used as a means of combining the species richness (total number of species and the extent to which all species are common).

Statistical analyses: Paired t-test was used to compare the vegetation density and biomass of grazed and protected depressions. Test of linearity between the two sites was performed using SPSS 17 software (SPSS 2008). Differences between means were considered significant if P values were ≤ 0.05. Means and standard error values are reported in each figure.

3. Results

Rainfall was 86 mm and 127 mm for the growing seasons 2007-2008 and 2008-2009, respectively. The rainfall was well below the average of the previous five years (Table 1).

Table 1. Seasonal precipitation (mm) at the weather station (Mgherat, Aleppo) nearest to the study site.

Growing season	Fall	Winter	Spring
2007 - 2008	18.4	44.2	23.4
2008 - 2009	23.4	66.4	38
Previous 5 years	30.2	95.96	45.2

3.1. Floristic characteristics

The plants species of the grazed and protected areas were catalogued. There were 74 species of higher flowering plants, belonging to 25 families and 65 genera (Table 2). The largest number belonged to family Poaceae: 13 species in protected area (17.6% of the total number of species), and 6 species in the grazed area (19.4%), followed by Asteraceae with 11 species in protected area (14.7% of total), and 3 species in the grazed area (9.7%), and Fabaceae with 7 species in protected area (9.5% of total), and 4 species in the grazed area (12.9%).

3.2. Plant density and biomass

Results (Figure 1) showed significant differences in both plant density and biomass ($P < 0.001$). Average plant density was 31 and 868 plants/m^2

Table 2. List of species in protected and grazed landscape depressions in Aleppo steppe, Syria during spring 2009.

	Protected		Grazed	
Family	**Number of species**	**% of species per family**	**Number of species**	**% of species per family**
Poaceae	13	17.6	6	19.4
Asteraceae	11	14.9	3	9.7
Fabaceae	7	9.5	4	12.9
Brassicaceae	6	8.1	2	6.5
Chenopodiaceae	5	6.8	3	9.7
Caryophyllaceae	3	4.1	0	0.0
Hyacinthaceae	3	4.1	0	0.0
Ranunculaceae	3	4.1	1	3.2
Euphorbiaceae	2	2.7	2	6.5
Lamiaceae	2	2.7	1	3.2
Malvaceae	2	2.7	1	3.2
Papaveraceae	2	2.7	0	0.0
Apiaceae	2	2.7	1	3.2
Zygophyllaceae	2	2.7	2	6.5
Alliaceae	1	1.4	0	0.0
Cistaceae	1	1.4	0	0.0
Cyperaceae	1	1.4	1	3.2
Dipsacaceae	1	1.4	0	0.0
Geraniaceae	1	1.4	1	3.2
Illecebraceae	1	1.4	1	3.2
Plantaginaceae	1	1.4	0	0.0
Primulaceae	1	1.4	1	3.2
Resedaceae	1	1.4	0	0.0
Rubiaceae	1	1.4	1	3.2
Scrophulariaceae	1	1.4	0	0.0
Total	74	100	31	100

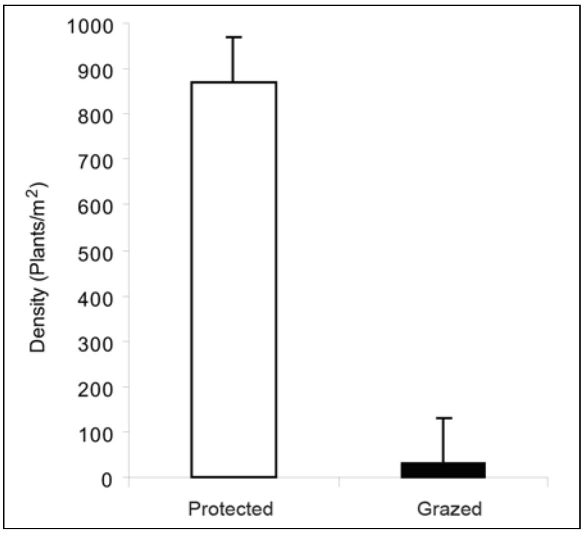

Figure 1. Plant density (number of plants m^{-2}) in grazed and protected landscape depression sites in Aleppo steppe, Syria during spring 2009.

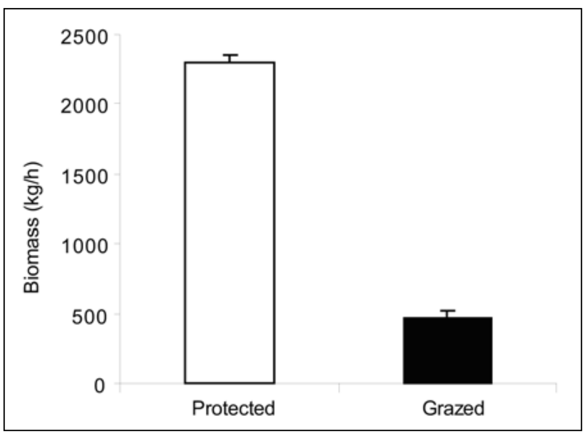

Figure 2. Biomass production (kg/ha) at grazed and protected landscape depression sites in Aleppo steppe, Syria in spring 2009.

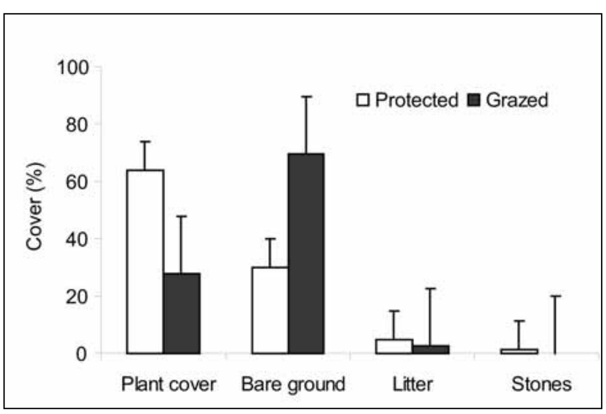

Figure 3. Percent cover in grazed and protected landscape depressions in the Aleppo steppe, Syria in spring 2009.

for grazed and protected depressions, respectively. The species density in the site open for grazing was mainly composed of the non palatable species, *Peganum harmala*, which is an invasive plant and an indicator of overgrazing, whereas in the protected depression there was a richness of moderate and highly palatable species.

Similarly, results for plant biomass showed highly significant differences ($P<0.001$) between the sites, 467 and 2,299 kg DM/ha respectively for grazed and non-grazed sites (Figure 2). In the grazed site, the majority of the biomass was composed of *Peganum harmala*.

3.3. Plant cover and diversity index

The development of vegetation cover (Figure 3) was significantly ($P<0.001$) different between the grazed and protected depression sites (28% versus 64%). Within the period of just two growing seasons, the plant cover on the protected depressions recovered and became more than double of that in the site open for grazing, without any other rehabilitation measures. Most of the vegetative cover in the grazed areas was composed of *Peganum harmala* (Figure 3). Similarly, percent bare ground was significantly ($P<0.001$) higher in the grazed area than in the protected area. The percentage cover of litter and rock represented a minor proportion of the total cover and the treatment differences were not significant.

Based on the vegetation sampling, the similarity index between the protected and grazed depressions was estimated at 54%. The index for diversity, Shannon Wiener index, ranged between 0.2 and 0.3 for the grazed area as compared to 2 to 2.5 for the protected area (Figure 4).

3.4. Life form and palatability

The analysis of the flora in the protected depression sites according to the life forms (Table 3) revealed that therophytes (annual forbs) were predominant, with 41 species (55.4 % of total species), followed by therophytes (annual grasses) with 12 species (16.2%), and perennial forbs with 7 species (9.5%). In the grazed depressions, therophytes (annual forbs) were predominant with 17 species (54.8 % of total species), followed by therophytes (annual grasses) with 5 species (16.1%) and chamaephytes (semi-shrubs) with 4 species (12.9%).

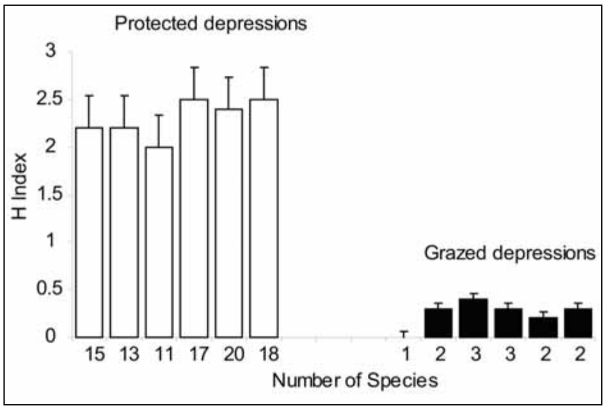

Figure 4. Shannon diversity index (H) of the vegetation at six sampled positions in the grazed and protected landscape depression sites in the Syrian steppe in spring 2009.

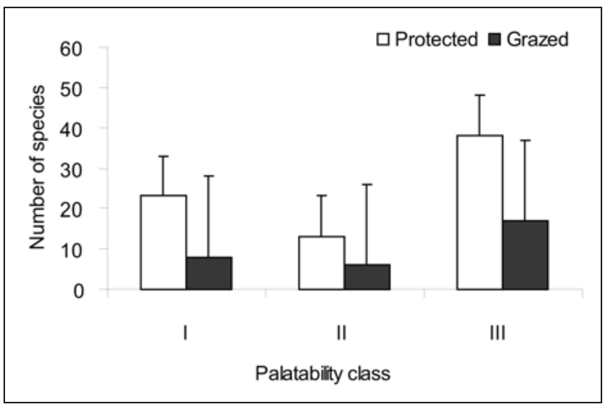

Figure 5. Palatability of species found in the protected and grazed landscape depression sites in Aleppo steppes during spring 2009. Classes: I = high palatable; II = medium palatable; III = low-unpalatable.

In the protected depression site, there were 23 highly palatable (i.e. Class I) species, whereas in the grazed site only 8 such species were found. For species with average palatability (i.e. Class II), 13 were recorded in the protected sites compared to 6 species in the grazed site. The number of the Class III species (representing low-or non palatable plants) was also higher in the protected site with 38 species, with only 17 species in the grazed area (Figure 5).

4. Discussion

This study sought to assess whether short term exclusion of livestock grazing would lead to different vegetation compositions in grazed versus protected landscape depressions in the steppe in Aleppo province, as this information could add to the debate concerning the resilience of arid ecosystems to livestock grazing. In fact, numerous studies have shown that continuous grazing of range species can have negative impacts on plant succession and regeneration because it removes leaf area that is necessary for producing photoynthates needed for regeneration (Ahmed et al. 2006; Briske and Richards 1995; Caldwell et al. 1981; Mosallam 2007). Rangelands in the Syrian steppe have experienced similar plant removal from uncontrolled herbivory and that has resulted in the dominance of unpalatable shrub species such as *Noaea mucronata* and *Peganum harmala* (Al-Oudat et al. 2005).

The spatial distribution and abundance of plant species and communities in arid and semi-arid ecosystems has been closely associated to a variety of physical and environmental variables linked to water availability and anthropogenic disturbance. Human activities associated with livestock grazing have a major potential influence on soil physical and chemical properties, vegetation patterns, and the relative abundance of palatable and unpalatable species and of woody and herbaceous cover (Dasti and Agnew 1994). The fluctuating and generally low precipitation has acted as a barrier to illegal cultivation of the Syrian steppe. However, the landscape feature of depressions that permits collection of soil and water even in the harsh climatic conditions has made them particularly vulnerable to such illegal encroachment. Natural vegetation productivity is an important measure of ecosystem function for arid ecosystems. Net primary productivity (biomass) in arid ecosystems varies with plant community composition, climate (temperature and precipitation), disturbance (grazing), topography, and the interaction of these factors (Clark 1973; Gibson 2009). In the spring of 2009, the above-ground biomass was 467 and 2,299 kg DM/ha, respectively, for the grazed and non-grazed depression sites. This suggests that rest as a rehabilitation measure has great potential to increase the above-ground biomass, particularly of grasses in the *wadi* areas. This is important for the Bedouins as they will be able to get forage and reduce the feed supplementation of livestock during dry periods.

Furthermore, reduced vegetation cover and lower plant species richness were recorded for the grazed depressions, clearly indicating the negative impact of continuous livestock grazing, as also reported by many other studies (Barth 1999; Peer

Table 3. Life-form distribution of surveyed species of protected and grazed landscape depressions in Aleppo steppe, Syria during spring 2009.

Life form	Protected		Grazed	
	No. of species	%	No. of species	%
Chamaephyte (semi-shrub)	6	8.1	4	12.9
Phanerophyte (shrub)	2	2.7	1	3.2
Geophyte (perennial herb with bulb or tuber)	4	5.4	0	0.0
Perennial grass	2	2.7	2	6.5
Perennial forb	7	9.5	2	6.5
Therophyte (annual forb)	41	55.4	17	54.8
Therophyte (annual grass)	12	16.2	5	16.1
Total species	74	100	31	100

et al. 2001; Louhaichi et al. 2009). One of the key indicators for the assessment of vegetation cover is the diversity index. The diversity index (Shannon wiener Index) explains both the richness and abundance for each site and is a good indicator for the health and resilience of the natural plant community to the induced stress. There was large (over 10 fold) difference in species richness and abundance as a result of grazing in the studied depression sites (Figure 4). This is also another sign that degraded depressions can be restored to their potential productivity in a relatively short period of time by protection from grazing.

Motyka's similarity index was used to assess the similarities in species composition in the two depression sites and the degree to which the species are shared. The similarity index was estimated at 54% which indicates that there is considerable difference between the grazed and protected depression sites.

Therophytes constituted the most abundant life form (Table 3) both under grazed and ungrazed sites indicating that theses depressions are disturbed, a condition which has resulted from human activities such as overgrazing and uprooting. The important and chronic disturbance leads to the decrease of the flora richness and the replacement of perennials by annuals (Ouled Belgacem et al. 2008). Both phanerophytes and chamaephytes place their buds higher off the ground and are therefore more sensitive to grazing compared to plants that maintain their buds at ground-level or below the soil surface (Liddle 1975). The number of therophytes in ungrazed sites was more than double of the grazed plots. These findings are in line with several studies that also report changes in plant species composition as a result of continuous grazing (Smith and Schmutz 1975; Noy-Meir et al. 1989).

Floristic changes induced by continuous grazing include the replacement of palatable plants by unpalatable plants in the unprotected depression sites. This was clearly evident from the dominance of unpalatable species *Peganum harmala* (an indicator of excessive grazing) in the grazed area. It is hypothesized that selective defoliation of palatable species allows unpalatable species to realize a competitive advantage. Noy-Meir et al (1995) also indicated that under long term intensive grazing the shift in species composition frequently involves the replacement of palatable plants by unpalatable plants (or) woody perennials. As illustrated in Figure 5, the number of species in our study for all the three palatable classes was higher for the protected depressions than in the grazed ones. This is in line with what was reported by Bottaro (2007).

5. Conclusions

Livestock have been herded in the *badia* rangeland by nomads for meat and milk production for millenia, and continuous grazing is the dominant practice used by Bedouins. Our study contributes to the regional literature documenting arid and semi-arid rangeland decline in North Africa and West Asia, and demonstrates a simple means to reverse the negative trend. The results clearly indicate that improved grazing system is a promising tool for a sustainable rangeland rehabilitation and management of arid ecosystems, necessary for the improvement of the Bedouins' livelihood.

In particular, the lowland areas (depressions) in the steppe, which, because of their physiography, have high production potential, if managed properly, can play an important role is providing feed for livestock especially in dry seasons. The productivity of the protected depression averaged more than 2 tons/ha/year, and the plant diversity was also higher compared to the continuously grazed depression colonized by unpalatable *Peganum harmala*.

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Role of soil organic matter and balanced fertilization in combating land degradation in dry areas and sustaining crop productivity

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Abstract

Land degradation means reduced potential productivity of soils at a fixed level of output. It is a widespread problem throughout the tropics and subtropics and a major issue because of its adverse impact on agricultural productivity and sustainability. Cultivated lands are being degraded by salinity and sodicity and irrigation through poor quality ground waters. The soils of dry areas are very deficient in organic matter. The degraded lands are estimated to cover around 158 million hectares in India. Restoration of these lands is of prime importance for both economic and ecological reasons. There is a tremendous potential to sequester C through restoration of degraded ecosystems.The soil organic carbon (SOC) pool constitutes one of the five principal global C pools, others being oceanic, geologic, atmospheric and biotic. The rate of depletion of SOC in soils of the tropics is exacerbated by the onset of soil degradative processes. Although the amount of SOC in soils of India is relatively low (typically less than 0.5%), its influence on soil fertility and physical condition is of great significance. It is extremely important to maintain SOC at a reasonable stable level by adding organic manures and crop residues, to maintain the productivity of the soil. Long-term experiments in different agro-ecoregions of India have shown that balanced use of NPK fertilizers also helps in maintaining SOC. The encouraging results obtained by integrated use of fertilizers, organic and green manures, and bio-fertilizers have helped in formulating future strategies for their rational use to enhance the productivity of agriculture in India in a sustained manner, without detriment to the environment.

Keywords: balanced use of fertilizers, carbon sequestration, land degradation, organic carbon, sustaining crop productivity.

1. Introduction

It is well recognized that soil organic matter is of fundamental importance for maintaining soil fertility and sustainable crop productivity. It holds essential plant nutrients, affects soil physical, chemical and biological properties, and provides energy material for the soil organisms. It also acts as a sink for green house gases (Swarup 2008a). The soil organic carbon (SOC) pool constitutes one of the five principal global C pools, others being oceanic, geologic, atmospheric and biotic. The rate of depletion of SOC in soils of the tropics is exacerbated by the onset of soil degradative processes including decline in soil structure, leading to crusting/ compaction and accelerated runoff and erosion, reduction in soil biotic activity, leaching of bases and depletion of soil fertility. Although the amount of SOC in soils of India is relatively low, ranging from 0.1 to 1% and typically less than 0.5%, its influence on soil fertility and physical condition is considerable (Swarup et al. 2000).

The cause of low level of organic carbon in Indian soils is primarily high temperature prevailing throughout the year. Organic carbon level of soil reaches an equilibrium that is determined by a number of interacting factors such as precipitation, temperature, soil type, tillage, cropping systems, fertilizers, the type and quantity of crop residue returned to the soil, and the method of residues management. Conversion of land from its natural state to agriculture generally leads to losses of SOC. It may take up to 50 years for the organic carbon of soils in the temperate climate to reach a new equilibrium level following a change in management but this period is much shorter in a semiarid and tropical environment like India (Swarup 2008b).

Considering the nutrient removal by crops and supply through different sources under intensive cropping systems, it is seen that removal is far greater than supply. It is therefore important to maintain SOC at a reasonable stable level, both in quality and quantity, by means of addition of organic materials and/or crop residues. Long term experiments in different agroecoregions of India, involving a number of intensive cropping systems and soil types, have proved that even balanced use of NPK fertilizer helps in maintaining SOC. The encouraging results obtained by integrated use of fertilizers, organic and green manures, and bio-fertilizers are providing the leads for future strategies for sustainably enhancing agricultural productivity without detriment to the environment. Thus carbon sequestration in soils, i.e. increasing SOC in agricultural lands, through proper management practices, can provide not only the environmental benefit of reduced GHG emissions but also provide sustainability to agricultural production system.

2. Organic carbon stock of Indian soils

Soils of India, like most soil of the tropics, have long been categorized as low in organic carbon and nitrogen. Total SOC pool in different soils of India (Table 1) is estimated at about 21 Pg ($1P_g = 10^{15}$ g =1 billion metric ton) to 30 cm depth and 63 Pg to 1.5 m depth (Velayutham et al. 2000).The potential of soil organic carbon sequestration through restoration of degraded and desertified soils in India is about 10-14 Tg C per year (Lal 2004). The largest potential of increasing SOC stocks in soil lies in restoring soil fertility besides controlling desertification and erosion.

3. Soil degradation

Soil degradation is a major concern in agriculture because of among other factors non-judicious use of agricultural inputs and over exploitation of natural resources. An important soil degradation process in agricultural systems is the fertility depletion and loss of soil organic carbon. The decline in yield and fatigue in productivity have been noticed in various cropping systems in different agro-ecoregions in India. The efficiency of use of inputs, especially fertilizer, water, soil amendments and manures, depends on several factors including type of soil. Development of site-specific integrated plant nutrient supply (IPNS) and management strategy is therefore, a viable option for sustaining the productivity of cropping systems and reversing land degradation. The basic concept underlying IPNS is the maintenance or adjustment of soil fertility and plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of affectivity of all sources of plant nutrients in an integrated manner. It is an approach that is ecologically, socially and economically sound and environmentally safe.

Though India is a food surplus nation at present with about 200 million tones food grains production per annum, it will require about 7-9 million tones additional food grains each year if the population growth continues at the present rate. This challenge can be met by greater and more efficient use of mineral nutrients through fertilizers and organic sources. The results from several long term fertilizer experiments conducted in differ-

Table 1. Soil organic carbon (SOC) stock in different soil orders in India.

Soil order	SOC pool (Pg)	
	0-30 cm	**0-150cm**
Entisols	1.36	4.17
Inceptisols	4.67	15.07
Vertisols	2.62	8.78
Aridisols	7.67	20.30
Mollisols	0.12	0.50
Alfisols	4.22	13.54
Ultisols	0.14	0.34
Oxisols	0.19	0.49
Total	20.99	63.19

Source: Velayutham et al. (2000)

ent agro-ecological regions, involving diversified cropping systems and soil types, have shown that imbalanced fertilizer use, particularly the use of N alone, had a deleterious effect on soil productivity and the adverse effect was more when P was excluded than when K was excluded. The soil type affected the yield decrease, and it was in the following order for different soil types: Alfisols > Vertisols > Inceptisols > Mollisols. In a period of less than ten years, crop productivity in N alone plots came down to almost zero in Alfisols. Integrating organic manure (FYM @ 10-15 Mg ha^{-1}) with 100% recommended NPK fertilizer doses – the dose recommendation is based on the expected uptake of these primary nutrients by the crop; see Table 5 later in the text – not only sustained high productivity but also maintained fertility in most of the intensive cropping systems and soil types. The results established that the soil type is one of the most important factors affecting fertilizer use efficiency and crop yields. Therefore, sustained efforts are needed to improve and maintain this most important resource base through judicious integration of mineral fertilizers, organic and green manures, crop residues and bio-fertilizers so that it may sustain pressures of intensive cropping systems without getting irreversibly damaged.

Many factors influence the complex chemical, physical and biological processes that govern soil fertility and productivity. Changes in fertility caused by imbalance in fertilizer use, acidification, alkalinity and declining soil organic matter (SOM) may take several years to appear. These properties in turn can be influenced by external factors such as atmospheric pollution, global climate changes or land use management practices. Long-term experiments provide the best possible means of studying changes in soil properties, nutrient dynamics and processes and identifying emerging trends in nutrient imbalances and deficiencies so that appropriate future strategies for maintaining soil health can be formulated. Agricultural scientists have long recognized the value of long-term experiments in studying the agro-ecosystem dynamics. The emphasis on such studies has been because of the belief that “certain soil processes are long-term in nature and must be studied as such”.

Dawe et al (2000), Powlson et al (1998), Swarup (2001), Swarup and Wanjari (2000) and Swarup et al (1998, 2000) have reviewed available data on yield trend analysis, soil properties and key sustainable indicators such as organic carbon and pH under long-term experiments, and identified regional fertility constraints and opportunities to increase agricultural productivity through integrated plant nutrient supply (Swarup and Gaunt 1998; Swarup 2004). The key results from these experiments are briefly presented below.

4. Effects of long-term fertilizer use on soil quality and crop productivity

The responses to fertilizers were in the order of NPK>NP>N but the degree of response to individual nutrients varied with the locations. The response declined, in some cases sharply, even after a few years. The decline was more when high yields were obtained continuously for a number of years with high doses of NPK fertilizers, because of a severe drain of other essential plant nutrients, making them a limiting factor for crop production. At the locations having Vertisols or Vertic Ustropept type of soils, such as at Jabalpur and Coimbatore, P deficiency was so severe that without its application crop yields were extremely poor and the benefits of N and K application could not be realized.

Addition of Zn and S became essential after a few cycles of intensive cropping at most of the locations. Thus, next to N, P and K, the deficiency of Zn and S is becoming the major yield limiting factor in most of the intensive cropping systems in India and appropriate changes in fertilizer use policy are needed for sustaining high productivity. Application of farmyard manure at the rate of 10 to15 t/ha along with NPK at standard rates maintained productivity for a long period without the need of application of other macro or micronutrients. This was perhaps because FYM was providing the missing nutrients. It has to be recognized that 15 tons of FYM of an average quality can add 75-100 kg N, 50-75 kg P_2O_5 and 170-200 kg K_2O per hectare besides other secondary and micronutrients. The effect of FYM was particularly conspicuous in Alfisols at Palampur, Bangalore and Ranchi; in Mollisol at Pantnagar, and in Vertisol at Jabalpur. The effect of NPK+FYM treatment was more conspicuous on maize than on wheat in the ‘maize-wheat’ cropping system at Palampur and Ludhiana. In these cases the improvement of soil physical conditions and additional supply of N, P, K, Zn and S could have produced synergistic effects.

The results on the phase of application of various nutrients showed that applying P, K, Zn and S to the more responsive crop in the sequence was better for overall efficiency. For instance, in a 'rice-wheat' system application of P to wheat and that of K, Zn and S to rice proved more beneficial. Similarly, in the 'maize-wheat' cropping system Zn, S and FYM application to maize was more beneficial than to wheat.

Other important results obtained from the long term trials are summarized below:

1. Yield showed decline when imbalanced fertilizer use continued for long periods.
2. Yield stagnated or declined when input levels were kept constant and/or were sub-optimal.
3. Continuous cropping without adequate inputs decreased soil N, P and K content.
4. On acid soils, application of N alone aggravated the problem of acidity. Application of lime improved the productivity, but for realizing full yield potential of the system liming had to be combined with optimum dose of NPK (Table1). FYM application also helped in yield improvement in acidic soils perhaps because of some buffering effect. Similarly, on the alkali soils of the Indo-Gangetic plains, application of gypsum, based on gypsum requirement of soil, was essential for attaining high yields, maximizing nutrient use efficiency and improving organic carbon status of the soils (Table 2).

Continuous use of NPK+ FYM treatment for 'maize-wheat-cowpea' cropping system at the Indian Agricultural Research Institute (IARI), New Delhi sustained the crop productivity and sequestered substantial amount of organic carbon in the soil (Fig.1). The carbon sequestration potential under 100% NPK+FYM treatment was quantified as 997kg C/ha/yr which could have great significance in mitigating climate change. Taking into consideration all the area under this cropping system in the semi-arid subtropical India, Purkayastha et al (2008) calculated that adoption of this balanced fertilization in 'maize-wheat-cowpea' cropping system might sequester 1.83 Tg C/yr, which corresponds to about 1% of the fossil fuel emissions by India.

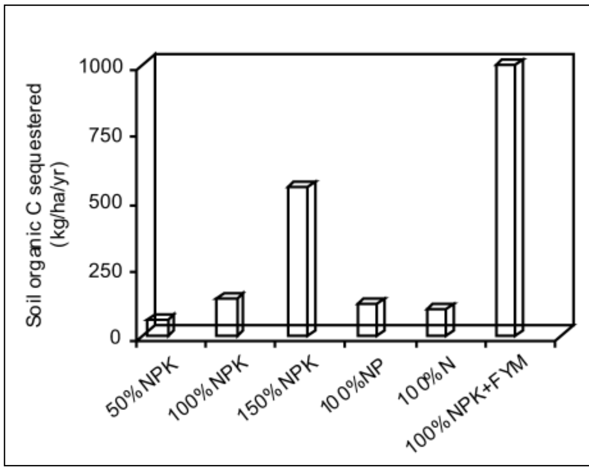

Figure 1. Effect of continuous application of different fertilizer treatments on carbon sequestration under 'maize-wheat-cowpea' cropping system on sandy loam soils at IARI, New Delhi.

5. Factors affecting soil organic carbon dynamics

The maintenance of soil organic carbon (SOC) in agricultural soils is primarily governed by climate, particularly annual precipitation and temperature,

Table 2. Soil properties (pH and organic carbon content) and grain yield under a 'maize – wheat' cropping sequence in a long term fertilizer experiment at Ranchi after 28 years.

Treatment	pH	Organic C (%)	Grain yield (Mg ha^{-1})	
			Maize	Wheat
	6.1	0.54	0.50	0.76
N	3.3	0.56	0.11	0.12
NP	3.4	0.61	0.55	1.20
NPK	3.5	0.64	0.80	1.70
NPK+Lime	6.7	0.61	4.16	4.10
FYM	6.4	0.93	2.80	2.50
Initial soil level	6.0	0.53	-	-

Source: Sarkar (1998)

Table 3. Effect of long-term *Sesbania* green manuring on sustainability of 'rice-wheat cropping' system and soil properties in a gypsum amended sodic soil.

Treatments	Average grain ($Mg\ ha^{-1}$)		Soil properties after 1992		
	Rice 1985-91	Wheat 1985-92	Org. C ($g\ kg^{-1}$)	Olsen's P ($kg\ ha^{-1}$)	pH
Fellow-rice-wheat	5.4	2.7	2.3	13.5	8.8
Green manure-rice-wheat	6.8	3.6	3.8	36.7	8.5
LSD (P=0.05)	0.5	0.5	0.3	4.5	

Source: Swarup (1998)

and cropping systems. Intensive cropping and 'tillage systems have led to substantial decreases in the SOC through enhanced microbial decomposition and through wind and water erosion of inadequately protected soils. Carbon loss by tillage is caused by greater oxidation of SOC and it ranges from 20 to 50% in soils of the semiarid regions of India. In most parts of tropical cropping systems, little or no agricultural crop residues are returned to the soil which leads to a decline in SOC content.

Parton et al (1987) observed that there are five different kinds of SOC pools (Table 4) in the soil: (1) a metabolic pool with 0.1 to 1 year turnover time; (2) a structural pool with 1 to 5 years turnover time, (3) an active pool consisting of living microbes and microbial products along with soil organic matter with a short turnover time (1 to 5 yr); (4) a slow pool of C and N that is physically protected and/or is in a chemical form resistant to decomposition with an intermediate turnover time (20 to 40 yr); and (5) a passive fraction that is chemically recalcitrant with the longest turnover time (200 to 1500 yr).

The soil microorganisms play a major regulatory role for organic carbon dynamics. The abiotic factors (temperature, moisture, soil type, nature and quantity of residues) may have a large impact on soil organic carbon dynamics by virtue of their effect on microbial activities. In subhumid and semiarid tropical ecosystem cropping systems, the turnover rate of SOC is much less as compared to that in forest land (Table 5). The rate of mineralization depends on tillage, resides management, cropping practices, and erosion. Materials having wide C: N ratios are resistant to decomposition because of limiting supply of nitrogen for organisms. The C: N ratio of the decomposed materials range from 10 to 15:1, which is better for supplying nutrients to plants. Application of the cereal straws (C: N ratio 80 to 120: 1) results in rapid immobilization of nutrients.

Long-term fertilizer experiments conducted over 25 years in different agro-ecoregions of India involving a number of cropping systems and soil types have shown a decline in SOC as a result of continuous application of fertilizer N alone (Swarup 1998). Balanced use of NPK fertilizer either maintained or slightly enhanced the SOC over the initial values. Application of FYM and green manure improved SOC. Considering the nutrient removal by crops and supply through different sources under intensive cropping systems, it is seen that removal is far greater than the supply. It is, therefore, extremely important to maintain SOC at a reasonably stable level, both in quality and quantity, by applying organic materials or

Table 4. Soil organic carbon functional pools, their turnover time and composition.

Functional pools	Turnover time (years)	Composition
Metabolic litter	0.1 - 1	Cellular compounds, shoot and root biomass
Structural litter	1 - 5	Lignin, cellulose, hemicelluloses, polyphenols
Active pool	1 - 5	Soil microbial biomass carbon, soluble carbohydrates extracelluler enzymes
Slow pool	20 - 40	Particulate organic matter (50 µm-2.0 mm)
Passive pool	200 - 1500	Humic acid, fulvic acid, organic mineral complex

crop residues. Jenny and Raychaudhuri (1960) concluded that fertilization with mineral nitrogen compounds along with additional nutrients would greatly enhance crop yields and stimulate the root system in the soil, which would augment the soil humus and bring it to a new higher steady level to the benefit of plant growth and soil management. Soil and crop management practices that are now being perfected in different agro-climatic regions of India represent a new philosophy of land use to sustain maximum crop production per unit time per unit of land with minimum soil degradation.

Some important benefits of SOC in low-input agro-ecosystems are the retention and storage of nutrients, increased buffering capacity, better soil aggregation, improved moisture retention, increased cation exchange capacity, and acting as a chelating agent. The addition of organic carbon improves soil structure and tilth, activates a very large portion of inherent microorganisms and reduces the toxic effects of pesticides.

6. Enhancing nutrient and water use efficiency for maximizing and sustaining crop production

Efficient management of nutrients constitutes one of the most important factors to achieve agronomic and environmental targets of intensive crop production systems. Agricultural intensification requires increased uptake of nutrients by crops. The depletion of nutrient reserves from the soil is a hidden form of land degradation (Swarup and Ganeshmurthy 1998; Swarup et al. 2000). In contrast, excessive application of nutrients or inefficient management leads to environmental problems, especially if large quantities of nutrients are lost from the soil plant system into water or air. Accomplishment of the enhanced rate of productivity requires that soil fertility be either enhanced or at least sustained at the present level. Recently, concerns have been raised regarding consequences of fertilizer use, more particularly of N fertilizers. This makes sense as recovery efficiency of N seldom exceeds 50 percent. A major portion of applied fertilizer is lost from soil plant system by leaching, run off, denitrification and volatilization and pollutes the soil, water and air.

Intensive cropping invariably results in heavy withdrawal of nutrients from soils and its success largely depends upon the judicious application of inputs commensurate with the nutrient uptake. The nutrient uptake values generally provide a reliable estimate of the nutrient needs of the crops for developing sound fertilizer recommendation strategies to attain sustained high productivity with maintained soil fertility. The average uptake of major nutrients by the crops at 100 percent NPK fertilizer treatments of selected intensive cropping systems is presented in Table 6 (Swarup 2006).

It is apparent that nutrient removal (NPK) can be as high as 620 kg/ha/year. In general, the exhaustive cropping systems in respect of nutrient removals are ‘rice-wheat’,‘rice-rice’, ‘maize-wheat’ and ‘soybean-wheat’. A look at differences between the nutrients applied and the nutrient uptake with optimal 100 per cent NPK dose indicated a positive balance of N and P and negative in respect of K on almost all the soils.

At the national level it is estimated that annually 34-35 million tons (MT) of nutrients are removed from the soil in India, whereas only 24-25 MT are supplied as fertilizers and organic sources thus

Table 5. Carbon pools of subhumid, semiarid tropical and arid ecosystems under different land management practices.

Carbon Pools	Sal forest	Mixed forest	Pearl millet-wheat -fallow	Pearl millet-mustard- sun-flower	Soybean-wheat- follow
Soil organic C (g m^{-2})	2854	2530	1063	1104	1144
Carbon input (g C m^{-2} yr^{-1})	250	250	281	365	265
Turnover(yr^{-1})	11.41	10.12	3.78	3.02	4.47
Soil microbial biomass C (g m^{-2})	87	90	42.30	31.70	50.8
C input/soil microbial biomass C	2.87	2.78	6.64	11.51	15.74

Swarup et al. (2000)

Table 6. Nutrient uptake in long-term fertilizer experiments under intensive cropping systems in India.

Cropping system	Soil type	Yield (t/ha)	Nutrient uptake (kg/ha/year)			
			N	P	K	Total
Maize-wheat-cowpea (F[1])	Inceptisols	6.8 - 0.6	240	45	250	535
Rice-wheat-jute fibre	Inceptisols	6.5 – 1.5	250	50	275	575
Maize-wheat-cowpea (F)	Mollisols	9.5 – 1.9	260	65	295	620
Rice-rice	Inceptisols	6.2	150	40	175	365
Soybean –wheat	Vertisols	6.3	285	44	225	554
Soybean –wheat	Alfisols	4.2	220	35	170	425
Fingermillet –maize	Alfisols	6.5	210	42	215	467
Fingermillet –maize	Inceptisols	6.5	245	40	270	555
Groundnut-wheat	Alfisols	2.9	106	18	65	189
Sorghum-hybrids sunflower	Vertisols	2.9	89	42	117	248

[1]Fodder

leaving a negative balance of about 10 MT. This could have serious consequences for sustained food security as the productivity would decline with increasing shortfall in the return of the nutrients and rising nutrient imbalance in the soil. For feeding a population of 1.4 billions by 2025, India will need to produce 311 MT food grains. This level of grain production will necessitate at least 45 MT of the three major plant nutrients, out of which at least 35 MT should come from chemical fertilizer sources (about 5.6-8.8 MT P_2O_5 + 2.3 to 4.7 MT K_2O and the rest nitrogen). At least 10 MT nutrients should come from organic manures, crop residues and bio-fertilizers.

7. Fertilizer use efficiency and environmental consequences

Fertilizer use efficiency (FUE) varies widely and usually decreases as fertilizer rates increase. Nitrogen use efficiency, based on grain yield, rarely exceeds 50 to 60 percent and can be as low as 20 per cent. First year FUEs are normally 10 to 30 percent for P and 20 to 60 percent for K, although they can be greater over the long-term because of the residual properties of these immobile nutrients (Swarup 2002). A recent review of worldwide data on N use efficiency for cereal crops from researcher managed experimental plots reported that single year fertilizer N recovery efficiencies averaged 65% for corn, 57% for wheat and 46% for rice. However, experimental plots do not accurately reflect the FUEs obtainable on-farm. Differences in the scale of farming operations and management practices lead to this difference. Nitrogen recovery in crops grown by farmers rarely exceed 50% and is often much lower. A review of best available information suggests average N recovery efficiency on farmers' fields ranged from ~ 20% to 30% under rainfed conditions and ~ 30% to 40% under irrigated conditions. In India, N recovery averaged 18% for wheat grown under poor weather conditions, but 49% under good weather conditions. Fertilizer N recovery is impacted by management, which can be controlled, but also by weather, which cannot be controlled. Thus there is a possibility to improve N use efficiency at the farm level. The best management practice (BMP) for achieving optimum nutrient use efficiency is applying nitrogen (nutrient) at the right rate, at the right time and in the right place.

Fertilizer N, P and K after their application in soil undergo transformation in physical, chemical and biological processes. For example, dynamics of N in the soil-plant-atmosphere system includes various soil processes (mineralization, immobilization, urea hydrolysis, nitrification, volatilization, denitrification and N movement in soil), the processes pertaining to above ground plant growth, and nitrogen uptake by crops. Soil type is one of the most important factors in affecting fertilizer use efficiency (Kumar et al. 1995; Swarup 2002).

Phosphorus after its application in soil is either removed by crop or gets immobilized into various insoluble forms (Fe and Al-phosphate and Ca-phosphate depending on pH of the soil) and gets fixed in soil clays or organic matter. The use efficiency of P does not exceed 20 percent. Significant amount of P is lost from the soil through surface run off and erosion resulting in eutrophication of water bodies.

Potassium is the most abundant plant nutrient in soil having illitic type of clay mineral. It is more mobile than phosphate and is susceptible to loss by leaching, run off and erosion. The K use efficiency is about 70 percent. Loss of K is a waste but carries no environmental concern.

The major environmental consequences related to fertilizer use are: in nitrate pollution of ground water; (ii) eutrophication ; (iii) ammonia volatilization; (iv) acid rain; v green house affect; (vi) damage to crops and soil organisms and (vii) trace element and heavy metals contamination (Swarup 2006).

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Soil carbon sequestration – can it take the heat of global warming?

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Abstract

Expectations are raised that soil organic carbon (SOC) sequestration could be a viable strategy to mitigate the impact of climate change. This paper highlights knowledge on the impact of climate change and land use change on SOC, the importance of likely emissions from permafrost soils, and current modeling capacities for simulating climate change induced SOC changes. We summarize estimates published in the literature on technical potentials for SOC sequestration and complement these with our own estimates for Central Asia. In conclusion, it can be stated that SOC-sequestration by improved land-management is possible, but the mitigation potential on a global scale is very limited. Soil carbon sequestration cannot thus take away the heat of global warming. In the dry areas, where decisions on crop residue management are dominated by the high value of crop residues as livestock feed, implanting SOC sequestration by surface crop residue retention from an economical point of view is quite unattractive. Such practices are more likely to be adopted, if they secure the resource base and guarantee food security.

Keywords: anthropogenic CO_2 emissions, carbon sequestration, Central Asia, climate change

1. Introduction

In view of global climate change and the failure of the 2009 Copenhagen Climate Change Conference to agree to any binding treaty to reduce anthropogenic CO_2 emissions, other means to mitigate global warming are desperately sought after. Expectations are high that carbon (C) sequestration by biomass production and preservation/storage of at least part of this C could be a possible mitigation strategy ("carbon sink"). It has been repeatedly proposed that C-sequestration in the soil could significantly contribute to this sink (Batjes 1998; Lal 1999, 2009). Lal (2002) even states that "the strategy of soil C sequestration is a bridge to the future; it buys us time until other energy related options could take effect."

This paper dwells on this issue. We provide a brief overview of worldwide C pools and anthropogenic emissions, and summarize current knowledge on the impact of climate change on soil organic carbon (SOC) pools as well as estimates published in the literature on technical potentials for SOC sequestration. As an example, SOC sequestration potentials of Central Asia, with the five countries Kazakhstan, Kyrgyzstan, Uzbekistan, Tajikistan and Turkmenistan, are presented. These estimates are based on losses of SOC in response to land use change quantified in a spatially explicit manner (Sommer and De-Pauw 2010). Finally, we examine the question as to how cost-effective C sequestration in soils of dry areas is, using rainfed wheat production in Syria as an example.

2. World carbon pools and emissions

Looking at the predominant global C-pools, it is clear that most of the carbon is found as dissolved CO_2 in the oceans (Table 1). Carbon is exchanged between the atmosphere and oceans, and thus oceans act as a considerable CO_2 buffer. It is estimated that about one third of the CO_2 released into the atmosphere by human activities has been absorbed by oceans, leading to considerable ocean acidification with (negative) consequences to the environment that only in last years have gained greater public attention (see e.g. Orr et al. 2005 and Choi 2009 for details).

Also less known in general, the largest fraction of actively cycling C in terrestrial ecosystems is found in the soil. Soils to 1 m depth store around three times the amount of carbon found in plants and animals or in the atmosphere. Of this SOC, Janzen (2004) estimated that about a third is in forest soils, another third in grassland, and the remainder in wetlands, cropland and similar other biomes.

Table 1. World carbon pools.

Pool	Amount (Pg C)*	Source
Ocean	38000-39000	IPCC (2001)
Atmosphere	785	Janzen (2004)
Biotic	466-835	Janzen (2004); Sombroek et al. (1993)
Geologic (coal, gas, oil)	4000-5000	IPCC (2001)
Soil, SOC•	1220-1550	Batjes (1996); Eswaran (1995); Post et al. (1982)
Soil, SIC£	750-950	Lal and Kimble 2000
Soil, total (1 m depth)	2000-2500	Janzen (2004); Amundson(2001); Eswaran et al. (2000)

* 1 Pg = 1 peta gram = 1000 Tg = 10^{15} g = 1 billion tons; • SOC = soil organic carbon £ SIC = soil inorganic carbon

Organic carbon in the upper meter of soil, and to some extent also in the deeper soils (see e.g. Sommer et al. 2000), is not inert. Cultivation of soil has lead to a tremendous loss of SOC in the past. Land use change, particularly in the tropics, often goes along with deforestation and rainforest burning and a substantial release of aboveground carbon into the atmosphere.

The net cumulative emissions of CO_2 (soil and aboveground) from the year 1850 to 2000 in response to human-induced land use change were estimated to be 156 Pg C (Houghton 2003). Currently, another ~1.6 (±0.8) Pg C is set free each year as CO_2 in response to land use change (IPCC 2001), contributing 16 % to the overall human induced emissions. The remaining 84%, i.e. 8.23 Pg C yr^{-1} (state: year 2006), comes from fossil fuel burning (gas, oil, coal, cement production and gas flaring; Boden et al. 2009; Table 2).

The 2006 emissions from fossil fuel burning increased by 34% (2.09 Pg C) compared to 1990 emissions, i.e. at an average annual rate of 1.8 % (130 Tg yr^{-1}). Emission increase was considerably faster from the year 2000 onwards (average 248 Tg yr^{-1}).

3. Impact of climate change and land use on soil organic carbon

As mentioned above, historic land use (change) is responsible for a tremendous loss of C from ecosystems. It has been detailed in numerous publications, commonly by comparing cultivated soils with neighboring virgin soils, that conversion of native land entails a significant loss of SOC (for more details see: Janzen 2004 and Smith 2008). Losses are largest where initial SOC stocks are largest, such as after conversion of peatlands or wetlands. On the other hand, the opposite trend might be observed, even though often at much slower speed, when degraded areas – unless irretrievably lost – are successfully restored.

In addition to the effect of land use, the impact of climate change on SOC dynamics and stocks is of importance, as it might either undermine or stimulate sequestration activities. Simulation studies by computer models are the only option to tackle the issue at global scale. This is not only because of the spatial dimension, but also because the effects of climate changes, e.g. a rising temperature, on the decomposition of SOC might only become visible after decades, given the long turnover time of the more recalcitrant organic matter fractions.

Table 2. Annual anthropogenic CO_2 emissions in response to fossil fuel burning and land use change.

Source	Amount		Reference
	Pg C yr^{-1}	%	
Fossil fuel burning			
year 2006	8.23	84	Boden et al. (2009)
year 2000	6.74		
year 1990	6.14		
Land use change	1.6	16	IPCC 2001
Total	9.83		

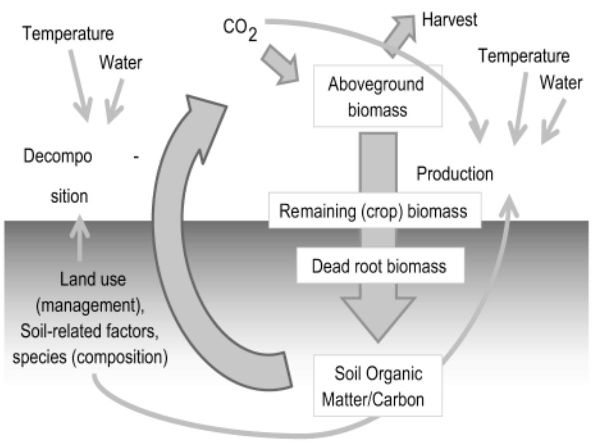

Figure 1. Conceptual view of the build-up and release of soil organic matter in mineral soils.

Figure 1 provides a conceptual overview of the build-up and decomposition (= release) of soil organic matter (SOM), of which carbon is the major constituent. Besides the more intrinsic, soil related factors (such as parental material, texture, cation exchange capacity), temperature, water and land use affect the production and the decomposition of SOM at the same time. Whereas knowledge on the impact of water (plant water availability, soil moisture, soil red-ox potential) on plant production and organic matter formation and decomposition is well advanced, the impact of temperature on soil organic matter dynamics remains to be fully understood and is subject of current scientific debate. It is the balance between production and decomposition that determines whether global warming leads to a negative or positive feedback on SOC stocks.

In a comprehensive review on the issue, Davidson and Janssens (2006) pointed out that a positive temperature sensitivity of decomposition of relatively labile, poorly decomposed SOM fractions is unquestioned. This means that soils with a high amount of this type of SOM, such as peatlands and wetlands, in a warmer world are likely to release vast amounts of CO_2, as long as the other constraining factors, above all water, are not limiting (see the example of permafrost soils given below). Yet besides labile SOM, upland mineral soils contain another significant fraction of SOM – "a 'veritable soup' of thousands of different organic-C compounds, each with its own inherent kinetic properties" (Davidson and Janssens 2006, page 167). Their intrinsic temperature sensitivity is not straight forward, but rather "obscured" by several environmental constraints, which themselves might be sensitive to (a changing) climate. The underlying feedback mechanisms are not fully understood, and simulation models – inevitably relying on such knowledge – therefore are currently not setup to predict the effect of a warmer world on SOC.

Smith et al. (2005) simulated the impact of climate change (period: 1990–2080) on changes in SOC of European croplands and grasslands. They predict that soils of these agro-ecosystems show a small increase in SOC on a hectare basis (1–7 t C ha^{-1} for cropland and 3–6 t C ha^{-1} for grassland). Considering the model uncertainties mentioned before, there is room for skepticism regarding the reliability of these predictions. Nevertheless, the important aspect of this study lies in the findings that land use change – in the particular, a predicted reduction in the area of cropland and grassland – overrides the positive per-hectare balance, and in total European cropland and grassland SOC stocks are predicted to decline. This is another example that the effects of climate change and land use change often go hand in hand, and therefore should be studied jointly.

Besides fossil fuel burning, thawing of permafrost soils in response to global warming without doubt is seen as the single biggest threat to earth's climate. Such frozen grounds cover 20 % of the earth's surface, and an approximate 400 Pg C is stored in the upper 3 m. By 2100, if global warming continues unabated, permafrost soils will have lost 100 Pg C (Gruber et al. 2004). On top of this, under such circumstances, permafrost thawing will boost methane release into the atmosphere. Emissions in response to thawing are estimated to be 20-40 % above what would be produced by all other natural man-made sources. This is equal to an extra increase in annual mean temperature of 0.32 °C on top of what is predicted otherwise by 2100 (Antony 2009).

4. Case study of Central Asia

Lal (2004) as well as Gintzburger et al. (2003) consider the potential of soils and agro-ecosystems in Central Asia to sequester C to be of global importance. In attempt to verify these statements, we estimated the SOC stocks in the upper 30 cm of pristine soils of Central Asia using the FAO-UNESCO (1995) Soil Map of the World and soil/

region specific literature data on SOC. Based on available information of losses of this carbon in response to land use by conversion of virgin land into rainfed or irrigated agricultural land as well as by degradation of rangeland, in combination with a land use cover (change) map recently released by ICARDA (Celis et al. 2007), we quantified losses of organic carbon in a spatially explicit manner (Sommer and De-Pauw 2010). According to these estimates, the OC stocks of pristine, i.e. undisturbed, soils of whole Central Asia in the upper 30 cm amounted to 21.09 Pg (Table 3). Conversion of virgin land into agricultural land and the degradation of rangelands were furthermore estimated to be responsible for a reduction of SOC contents by 874 Tg C, or 4.1 % of the total SOC stocks.

To this reduction, degradation of rangeland observed on 4.9 Mha with 217 Tg C contributed 25%. The bulk of the losses was caused by rainfed agriculture (70%, 613 Tg). Kazakhstan alone, given its size and the vast area under rainfed agriculture, was responsible for 87 % of the SOC losses. Nasyrov et al. (2004) showed that irrigated agriculture in desert areas improves the SOC status of the dominant (naturally poor) soils. Thus, these areas prevailing in Uzbekistan and Turkmenistan contributed positively to the SOC balance of these countries (negative numbers in Table 3).

Assuming, against all the existing obstacles, that improved agronomic and rangeland management, in addition to a restoration of drained wetlands (e.g. southeast of the shrinking Lake Balkhash in eastern Kazakhstan), could be put in place at large scale and instantaneously, and assuming that therewith SOC levels in all of Central Asia's cropland and degraded rangeland can be brought back to native levels in the next 50 years, on average 17.5 Tg C could be sequestered each year.

In 2006 the CO_2 emissions from fossil fuel burning in Central Asia amounted to 99.6 Tg C (Boden et al. 2009). Thus, the 17.5 Tg SOC sequestration potential represents 17.6% of the 2006 annual anthropogenic C-emissions. On the other hand, Central Asia is only a minor emitter of CO_2 (1.2 % of world total). In comparison to annual worldwide emissions from fossil fuel burning (8.23 Pg in 2006; Table 1), a sequestration potential of 17.5 Tg C represents merely 0.21%, which is far away from being of *global importance* as stated by Lal (2004) and Gintzburger et al. (2003).

If SOC-sequestration was eligible for the so-called Clean Development Mechanism projects within the framework of the Kyoto protocol, sequestering 17.5 Tg C per year, at a price of €13.03 per ton C (December 2009) are currently worth approximately 228 Million Euro.

It remains to be unraveled, whether this amount could compensate for the costs of implementing the necessary steps to achieve such sequestrations goals, and how long it would take until implementation – reaching even the most remote degraded rangeland spot – is completed.

5. Technical potentials to sequester carbon in soils

Similar to our study, others have also assessed the technical potential of SOC sequestration on global, continental or country-scale (Table 4). Some discrepancy exists between assumptions on anthropogenic global emissions. Paustian et al. (2004) mentioned 9.1 Gt yr^{-1}, which is close to

Table 3. Virgin soil organic carbon (SOC) stocks and losses in response to land use in Central Asia by country (Sommer and De-Pauw 2010).

Country	Virgin SOC (Tg)	Losses of SOC (Tg) by			Total losses	
		Rainfed agriculture	Irrigated agriculture	Rangeland degradation	(Tg)	(%)
Kazakhstan	16,399	498	95	168	761	4.6
Kyrgyzstan	1,405	40	18	7	65	4.6
Tajikistan	935	22	12	6	40	4.2
Turkmenistan	974	32	-47	23	8	0.8
Uzbekistan	1,378	21	-34	14	1	0.05
Total	21,090	613	44	217	874	4.1

the data of Boden et al. (2009; Table 1), whereas Smith et al. (2007) assumed 13.4 Gt yr^{-1}. The percentage estimates on potential SOC sequestration due to improved management are notably close ranging between 5-14 % of the total emissions.

It remains subject of further debate whether economically it is wise trying to reach the full technical potential of SOC sequestration. Other measures, such as afforestation of degraded areas or halting deforestation in the tropics, might contribute more to mitigating climate change at comparably much lower cost (as well as providing other important benefits such as biodiversity conservation).

It should also be noted that a considerable fraction of the predicted SOC sequestration potential is currently "consumed" by the rapid increase in CO_2 emissions from fossil fuel burning outlined earlier (Table 1).

6. Cost-benefit of SOC sequestration in rainfed wheat production systems of Syria

Earlier studies at ICARDA headquarters in the semi-arid northern area of Syria focused on the impact of residue retention (grazing), crop rotation and N-fertilization on wheat production (Ryan et al. 2010). Sommer and Ryan (2009) showed that over a period of 22 years, soils under rainfed, zero-tilled, continuous wheat with zero-grazing – i.e. 100 % residue (straw) retention – and an application of 60 kg N ha^{-1} (urea) and 39 kg P ha^{-1} (super-phosphate) might sequester around 280 kg C yr^{-1}.

Retaining the full amount of straw, which is 2 and 6 Mg ha^{-1} depending on the season, meant a loss of income from not selling straw equal to approximately 320-490 US$. On the other hand, sequestering 280 kg C ha^{-1}yr^{-1} at a price of 19.54 US$ per ton (13.03 € per ton) is worth only 5.47 US$. This means that, even if SOC was eligible for CDMs and tradable on the international carbon market, income from SOC sequestration alone would provide little incentive to farmers to retain straw on their fields.

However, SOC sequestration, i.e. the enrichment of the soil with SOM, supposedly also increases soil fertility, diminishes loss of water from the soil by evaporation and thus boosts crop yields. Such scenario is highlighted in Figure 2: Grain yield in northern Syria varies strongly from season to season and might be as low as ~0.50 Mg ha^{-1} in very dry years to as high as ~5.0 Mg ha^{-1} in years with favorable rainfall. Point A in Figure 2 marks the result of wheat production in a common year: 2.0 Mg ha^{-1} grain production and 3.7 Mg ha^{-1} straw production (corresponding Harvest Index, HI, 0.35). At a market price of 0.38 US$ per kg of grain and 0.13 US$ per kg of straw, the total income would be 1254 US$ (grain:768 US$, straw: 486 US$). Assuming that 100% residue retention could boost grain yield by 33% and the HI by 0.03, the income from grain production would increase by 194 US$ (point B). The loss of income from not selling the straw however would have been 486 US$. In total such investment (292 US$) into soil fertility increase therefore would be unattractive to farmers. The break-even point in this scenario would be a grain-production of at least 3.9 Mg ha^{-1}, i.e. almost double the common yield.

Table 4. Estimates of the technical potential of SOC sequestration due to improved management globally and in selected countries as compared to total carbon emissions (Chan et al. 2008, modified and extended).

Region	Total C emission	Potential SOC sequestration	% of total emission	Reference
	(Gt yr^{-1})		(%)	
Global	9.1	0.44-0.88	5-10	Paustian et al.(2004)
Global	13.4	1.5-1.63	11-12	Smith et al. (2007)
USA	2	0.288	14	Lal et al. (2003)
Europe	1.2	0.104	8.3	Smith et al. (2000)
Australia	0.154	0.013	8.4	Chan et al.(2008)
Central Asia	0.107	0.017	16	Sommer and de Pauw (2010)

Surely, our scenario represents a large simplification because a range of biophysical, economic and social factors as well as the dynamic nature of the problem – e.g. straw retention affects crop performance of the coming year only – are not taken into account. It nevertheless stresses the importance of considering the high value of straw in northern Syria, when assessing possibilities for surface residue retention. A viable compromise might be partial residue retention, such as by removing loose straw only and retaining tall stubbles. This might benefit soil fertility and soil moisture conservation while at the same time addressing the need to use straw for fodder or for sale. ICARDA is currently carrying out research on this issue.

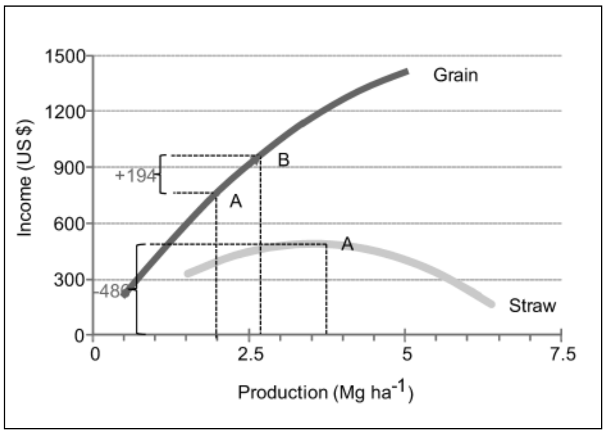

Figure 2. Gross-income from wheat production distinguished by grain and straw at different production levels; assumptions: price of grain linearly decreasing from 0.43 US\$/kg @ 0.5 Mg ha^{-1} to 0.28 US\$/kg @ 5 Mg ha^{-1}, price of straw linearly decreasing from 0.22 US\$/kg @ 1.5 Mg ha^{-1} to 0.02 US\$/kg @ 6.5 Mg ha^{-1}; production increase (A→B) due to 100% residue retention +33 % grain.

7. Conclusions

Climate change induced changes in SOC of mineral upland soils with a considerable fraction of less-labile SOM are difficult to assess, as the underlying mechanisms, above all the intrinsic temperature sensitivity, are not well understood. Possibilities for model application therefore currently seem rather limited, because today's findings cannot be extrapolated into a warmer future. On the other hand, there is evidence that soils with predominantly labile SOM, such as peatlands and wetlands, in a warmer world are likely to release vast amounts of CO_2. In that regard, arctic thawing and the release of methane and CO_2 in response to global warming is the single-most important climate change threat, dwarfing other sources of emissions.

Land use change is likely to "outperform" the CC-induced changes of SOC in many regions, which also means that halting land use change, such as deforestation in the tropics, could considerably contribute to the mitigation of climate change.

SOC-sequestration by improved land-management is possible, but its impact on a global scale is rather limited. In other words: soil carbon sequestration cannot take away the heat of global warming. Additionally, in the dry areas, where decisions on crop residue management are dominated by their high value as livestock feed, imposing SOC sequestration is quite unattractive from an economical point of view. Such practices are more likely to be adopted, if they secure the resource base and guarantee food security.

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Community-based reuse of greywater in home farming

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Abstract

With annual renewable water resources less than 150 m^3 per capita, Jordan is one of the most water scarce countries of the world. The demand for freshwater resources has been on the increase in the urban sector due to the economic development and population growth. The limited amount of water available for agriculture necessitates the use of non-conventional water resources, such as greywater, as an alternate option. Greywater refers to domestic wastewater generated by bath showers, hand basins, floor wastes, washing machines, and dishwashing, which has not been mixed by toilet wastes. This resource comprises about 50-80% of house water consumption in the rural areas. Its treatment and reuse offers an attractive option in arid and semi-arid regions due to its role in promoting the preservation of high-quality freshwater as well as reducing environmental pollution. Additional benefits include cost saving to both the consumer and state water authorities through reduced sewage flows and potable water supplies. In times of unpredictable rainfall resulting from climate change, greywater provides a reliable supply of water for home farming to irrigate high-value crops contributing to food security and income generation at household level. Greywater reuse research in Jordan, conducted mainly by the National Center for Agricultural Research and Extension (NCARE) in cooperation with several national and international organizations, reveals its high potential for irrigation of residential gardens, especially in rural areas. However, there is a need for further research in treatment and quality improvement to reduce environmental risks and enhance sustainable use. In partnership with the International Center for Agricultural Research in the Dry Areas (ICARDA), NCARE is addressing these aspects through community-based interventions.

Keywords: climate change, food security, greywater, Jordan, non-traditional water, water scarcity, environment protection.

1. Background

Greywater refers to the untreated household wastewater, which has not been contaminated by toilet waste. It includes water from bathtubs, showers, hand basins, laundry tubs, floor wastes and washing machines. Greywater represents 50-80% of the total water consumption at home. It is called 'grey' water because it turns grey if stored for a while (Al-Jayyousi 2002). Toilet water is generally called 'black water' or 'sewage' and in most literature, both are lumped together as 'wastewater'. This convenient label is misleading because greywater is very different from black water, and neither should be wasted. Both can be re-used for irrigation of residential gardens, but with different methods and levels of handling due to their basic discrepancies. Greywater is far easier, safer and cheaper to re-use compared to blackwater.

As greywater contains many impurities, including mineral nutrients (nitrogen, phosphorus, etc.), there is a possibility of harmful environmental impact, on the soil in particular. Great care must be exercised when designing land applications to ensure that they are sustainable. There are some chemicals that cannot be treated or get degraded in the soil and these may accumulate in the soil and increase the possibility for future pollution of surface and ground water. Therefore, soil ecosystem must be capable of adsorbing, absorbing, assimilating or treating the chemical impurities and nutrients without medium term and long term degradation of the soil and associated environment.

Domestic greywater treatment systems are designed primarily to treat organic matter and remove suspended material, and normally do not remove various chemical constituents including salts. Treatment processes to be employed will depend on the purpose and method of greywater utilization. The processes may include settling of solids, floatation of lighter materials, anaerobic digestion in a septic tank, aeration, clarification and finally disinfection. The treatment generally reduces only the gross primary pollutant. Secondary pollution may still occur because chemical components such as nitrates, phosphates, boron and sodium are not reduced.

The composition of greywater depends on household activities which vary according to socioeconomic status, cultural practices, cooking habits, cleaning agents used, and the demography. In general, greywater in low and middle-income countries may contain soaps, detergents, fibers from clothes, hair, suspended and dissolved solids, and grease and oil (Suleiman 2007).

Domestic greywater reuse offers an attractive option in arid and semi-arid regions due to severe water scarcity, rainfall fluctuation, and increased water pollution from inappropriate disposal. It contributes to saving high-quality fresh water as well as reducing pollutants in the environment. It can also result in cost saving (to both the consumer and state water authorities), reduced sewage flows and potable water saving of up to 38% when combined with sensible garden design (Al – balawneh 2006).

Greywater is suitable for restricted irrigation of lawns, trees (olive), ornamentals, and forages. The potential benefits of greywater reuse are:

- Lower fresh water extraction from aquifers;
- Less impact from septic tank and treatment plant infrastructure;
- Reduced cost to empty the septic tank;
- Topsoil nitrification;
- Reduced energy use and chemical pollution from treatment; and
- Increased growth and yield of plants due to the high levels of nitrate and phosphate beneficial to plants.

However, the quality of treated greywater is the main concern for researchers because it may contain a range of disease causing pathogens. Greywater is not allowed to be used in ponds or for surface irrigation systems because of the risk of mosquito breeding and contact with human skin and possible pathogen transfer. The wastewater also starts giving out foul smell after a day or two. Many pathogens such as bacteria (e.g. fecal coliforms) and protozoa (e.g. Giardia) may be present in some greywater sources. Greywater quality is characterized by the following properties:

- Higher salinity compared with fresh water (1-2.5 dS/m);
- Enrichment of detergents-released chemicals, mainly sodium, boron and surfactants;
- High BOD (Biological Oxygen Demand) value and highly enriched with coliform & fecal coliform; and
- High organic matter content and suspended solids.

These properties restrict the use of greywater for edible crops and plants sensitive to salinity and sodium (Bino et al. 2007).

In some countries, e.g. USA, wastewater from kitchen is not included in greywater. Greywater also does not include waste from garbage disposal units or dishwashers. It represents 50-80% of the total water consumption at home and can reduce the demand on fresh water resources. Greywater has been used for irrigation in many countries in the world like UK, Australia, Hong Kong, Japan and Cyprus. In the Middle East, in some regions including Jordan, Egypt, Yemen, Lebanon and West Bank, greywater reuse for irrigation has recently increased to meet the increasing demand for irrigation and the growing need to conserve fresh water resources for domestic use.

2. Greywater in Jordan

Jordan is characterized as one of the 5 poorest countries in water resources in the world (Qadir et al. 2009). The demand on water resources in Jordan has increased due to economic development and population growth. Among the efforts to overcome the increasing demand, there is a high interest in utilizing the non-traditional water resources (e.g. greywater) as an alternative, as they constitute about 50-80% of house water consumption in the rural areas of Jordan. The Jordan Water Strategy (2008-2022) acknowledges that wastewa-

Table 1. Efficiency of two and four barrels systems in greywater treatment.

System	BOD reduction	Cost (JD/unit)	Jordanian standards	Notes
Two Barrels	20%	200	Most parameters higher than the limits	Sharp odor problem
Four Barrels	30%	300		Odor problem

Table 2. Efficiency of one and two stages constructed wetland systems in greywater treatment.

System	BOD reduction	Cost (JD/unit)	Jordanian standards	Notes
One stage	75-66%	800	Within the limits	Limited odor problem
Two stages	85%	1200		

ter must be managed as a valuable resource to be collected and treated to meet standards that allow its reuse. The associated water policies reinforce this view. The wastewater management policy addresses issues pertaining to the protection of on-farm occupational health and consumer health where treated wastewater reuse is practiced. The Irrigation Water Policy encourages the reuse of treated wastewater in irrigation provided that appropriate standards and conditions are maintained. Moreover, Jordan's Strategy for Agricultural Development, as prepared by the Ministry of Agriculture, looks at irrigation with treated wastewater as an answer to Jordan's chronic water deficit.

The National Center for Agricultural Research and Extension (NCARE) has been conducting greywater research in Jordan in cooperation with several national and international organizations to find out its potential for safe irrigation of residential gardens, especially in rural areas. All results show that there is a good potential for its reuse to irrigate residential gardens to increase crop yield and economic return. However, there is still a need for new research in the fields of treatment to reduce the environmental risks and enhance its sustainable use (Qadir et al. 2009; Al balawneh 2003).

3. Jordanian experience in greywater reuse

Care International, in conjunction with the Inter-Islamic Network on Water Resources Development and Management (INWRDAM), has been distributing and installing greywater treatment units in villages of rural Jordan. These units consist of piping to capture greywater from the dwelling, plastic barrels for greywater treatment, automatic pump to take the greywater to the irrigation system, and irrigation piping and valves (NET Plan 2004).

Large scale greywater activities started in Jordan in 2000 by INWRDAM in Al-Karak and Al-Tafilah governorates (southern Jordan) in cooperation with NCARE. The project aimed to help local community to utilize greywater resources for irrigation at residential level, conserve fresh water resources, conserve the environment, and increase income. Results showed a good potential for reuse. The project met its objectives: scaling up of greywater use and improvements in design of low cost greywater treatment methods that are suitable for rural low income households. It resulted in governmental policy directions that encourage greywater use in rural home gardens. Also, the project succeeded in the introduction of comprehensive greywater use practices; greywater recovery and treatment, permaculture principles and local capacity for operation and maintenance (Bino et al. 2007).

In 2002, INWRDAM in cooperation with NCARE also installed around 750 greywater units of different types for the benefit of low-income families across Jordan through a project financed by the Jordanian Ministry of Planning and International Cooperation (MOPIC) and CARE International. Many types of greywater treatment systems have been used in Jordan since 2001. To evaluate the efficiency of these systems, research activities have been conducted at NCARE in two phases.

Phase 1 involved monitoring the efficiency of greywater systems already installed by other agencies. These included two systems: the two barrels system and four barrels system. Results showed that unfortunately these systems were not efficient enough to meet the Jordanian Standards (JS) for greywater reuse as shown in Table 1.

Phase 2 involved the establishment of the Constructed Wetland (CW) system for greywater treatment. The two CW systems were evaluated at NCARE: one and two stage CW systems. Results of their evaluation (Table 2) showed that the potential of the use of one stage CW system was better than of the two stage system.

The NCARE implemented a pilot project on greywater reuse for irrigation in Badia area (northeast Jordan) during the period 2002-2005. This project aimed to collect and treat the greywater by a CW system to help poor people conserve and utilize their water resources for irrigating high value crops, increase community participation in the national efforts to conserve water resources, and develop on-site, suitable, low cost and environmentally safe treatment method (Al balawneh 2007). The amounts of greywater generated from domestic uses ranged from 1-3 m3/week. The results showed that greywater effluent quality was suitable for restricted irrigation, mainly for industrial crops and forages. The CW system showed a good potential for greywater treatment and reduced level of pollutants (BOD, COD, EC and soluble salts). For example BOD values, which ranged 300-1000 mg/L before treatment, were reduced to 150-300 mg/L after treatment. The use of greywater reduced the demand for fresh water resources for irrigation. The average monthly water bill before project implementation was 32 JD/month; it got reduced to 22 JD/month after the use of greywater in irrigation, about 31% saving. The amount of wastewater delivered to the septic tank was also decreased, and, as a result, the septic tank had to be emptied on average only 2.5 times/year compared to about 4 times/year before the project, resulting in about 38% saving in septic tank pumping cost. Results also showed that it contributed to about 60% of home garden irrigation water requirements. Soil, water and plant samples were collected periodically and analyzed to monitor the impacts due to the use of greywater in irrigation. Results showed no adverse effects on olive tree quality, but only a slight increase in soil salinity (soil salinity reached 1.1-1.82 dS/m compared with 0.34-.96 dS/m before greywater use).

Finally, the project concluded that greywater reuse could be a valuable and alternative water resource on national level in rural areas of Jordan. There is however a critical need to conduct more research on a series of cost-effective greywater treatment technologies for use in urban and peri-urban agriculture to minimize environmental impacts associated with greywater reuse.

There are several actions that can be implemented at various levels to increase public participation in greywater reuse in Jordan. These include: additional studies to assess its overall impacts for wider sustainable use; integration of the system in the country water plan; emphasizing the importance of socio-economic factors; developing localized solutions that are simple, low-cost and easy to maintain; raising awareness at household level through advocacy campaigns, social advertising, and training; and developing regional networks for exchange of experience (Bino and Al-Beiruti 2007).

In spite of the progress made as shown above, there is still a need for further research in greywater treatment and quality improvement to reduce environmental risks and enhance community participation for sustainable use. In partnership with ICARDA, NCARE is currently addressing these aspects through community-based intervention to enhance reuse of greywater in home gardening and improving the treatment efficiency of the constructed wetland system with funding from the Coca Cola Foundation. This regional project includes Jordan, Lebanon and Palestine, and aims at: (1) raising public awareness regarding safe and productive use of greywater; (2) increasing availability of reliable and sustainable irrigation water resource; (3) increasing household income through better garden production, reduced water charges and decreased septic pool pumping costs; (4) reducing the environmental and health risks, and (5) enhancing regional cooperation on this issue.

The project is implemented in partnership with rural communities dealing with farming activities – later referred to as benchmark community or ‘main community’ – at a benchmark site in the Madaba governorate of Jordan where the households are not connected to a sewerage collection system. In the absence of the sewerage system, the households spend considerable amount for the collection and disposal of domestic wastewater. The 'main community' reflects the major challenges associated with the generation and disposal of domestic wastewater. Based on identical criteria, one demonstration site each in Lebanon and Palestine will be identified and referred to as 'collaborating sites'. The main community will be linked to the collaborating sites having similar characteristics to complement the work of the project-led interventions. The main community (the benchmark project site) will serve as a hub for capacity building and technology transfer as the research results and experiences will be exchanged between the main community and collaborating sites in Lebanon and Palestine. The intended beneficiaries of the project will be the farming communities using greywater for irrigation. Other beneficiaries will include the general public through awareness raising, partner institutes through capacity building, and society in general through best water management practices in the form of safe and productive use of greywater.

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Mycorrhizal fungi role in reducing the impacts of environmental climate change in arid regions

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Abstract

Global environmental change is one of the greatest challenges that humanity faces today. Increasing atmospheric CO_2 concentration is considered to be responsible for these changes. This is attributed mainly to anthropogenic factors associated with the increase in the world population. Little attention has been paid to the biological effects of rising atmospheric CO_2 concentrations, particularly on the soil symbionts (e.g. symbionts of mycorrhizal fungi) that occur in most biomes on Earth. The most common group of mycorrhizae is that of the arbuscular mycorrhizal fungi (AMF) that colonize the roots of over 80% of land plant families. Located at the plant–soil interface, AMF are potentially an important link in the chain response of ecosystems to elevated atmospheric CO_2. In addition to providing numerous benefits to host plants (e.g., improved plant growth, mineral nutrition, and tolerance to diseases and environmental stresses), AMF may play a critical role in carbon sequestration in the soil. As an obligate symbiont, AMF depend on the plant for their carbon source. Up to 20% of the total carbon assimilated by plants may flow to the soil mediated by mycorrhizae. The AMF also play an important role in enhancing the soil aggregation through secretion of sticky glomalin and thus increasing the ability of soil to retain carbon. This paper provides an insight into how mycorrhizal fungi might play a role in reducing the impacts of environmental climate change (especially the rising global CO_2) in arid regions.

Key words: arbuscular mycorrhizal fungi, climate change, elevated CO_2, global warming.

1. Introduction

Global environmental change is one of the greatest challenges that humanity faces today (Wyman 1991). A combination of rapid population growth, consumption of fossil fuels and industrial expansion has resulted in a steady increase in the quantities of greenhouse gases discharged into the atmosphere (Egerton-Warburton and Allen 2002). There is strong evidence that gas emissions contribute towards "global change", which encompasses a change in most climate variables, including global warming. The major gases responsible for these changes and global warming are carbon dioxide (CO_2), methane, the oxides of nitrogen (N_2O), chlorofluorocarbons (CFCs) and other gases (Figure 1). The greatest contributor is CO_2, accounting for about 56% of total emissions (Science-museum 2010). Therefore, this paper concentrates on the effects of CO_2 as a significant factor of global change.

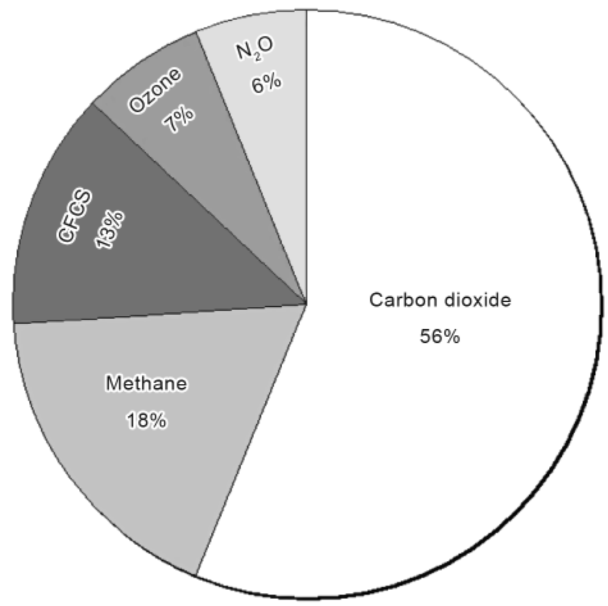

Figure 1. The relative importance of the major greenhouse gases in causing current climate change. Adapted from Science-museum (2010).

Land use and land cover are linked to climate and other environmental changes in complex ways, such as the exchange of greenhouse gases between plants, soils and the atmosphere. Much research into the biological effects of rising atmospheric

CO_2 concentrations and temperature has focused on plant growth and carbon fixation. As a general trend, a large proportion of the additionally fixed carbon in terrestrial ecosystem is channeled below ground, to plant roots.

Plant responses to limited water availability are expected to vary under the different scenarios predicted by global climate change models. Water availability is already an important factor in determining plant community structure in many arid and semi-arid environments and the International Panel of Climate Change (IPCC) has predicted increased drought occurrence for many of these regions. However, other crucial components of terrestrial ecosystems, especially in the soil, need to receive attention (e.g., mycorrhizal fungi). The major types of mycorrhizae are the arbuscular mycorrhizal fungi (AMF) which form symbiotic associations with plant roots and occur in the vast majority (about 80%) of terrestrial plants (Smith and Read 1997).

Mycorrhizal associations provide benefits to the host plant by alleviating stress in times of drought. The external fungal threads (hyphae) of AMF extend into the soil matrix beyond the root depletion zone and considerably improve the plants' exploration of the soil for nutrients, thus promoting the availability and the uptake of water and mineral nutrients from deep layers of soil (Al-Karaki 2002). At the ecosystem scale, AMF become important through their effects on soil aggregation in soils in which organic matter is the main binding agent. Soil aggregation, in turn, has important consequences for soil carbon storage (Six et al. 2000).

2. Rising atmospheric CO_2 and carbon sequestration in soil

The atmospheric carbon dioxide concentration has increased continuously over the past decades, mainly as a result of the use of fossil fuel and changes in land use; it is expected that the CO_2 concentration of the atmosphere will increase from the current 360 ppm to about 550 ppm in 2050 (Raven and Karley 2006). Elevated atmospheric CO_2 increases the C- availability for plants and thus leads to a comparable increase in plant growth and development especially at high nutrient availability (Poorter et al. 1996). However, about 70% of plant material returned to the soil is mineralized into CO_2 in a year, with only a small fraction becoming stable soil organic matter. The high amount of soil C is a general indicator of good soil quality (Doran et al. 1999).

Mitigation of global climate change can be partially achieved by C sequestration into soil (increasing the C sink of terrestrial ecosystems), most importantly through changes in land use and management (Lal 2003). Land use practices that result in a net accumulation of soil organic matter in the soil are said to be C sequestering because they result in a net removal of C from the atmosphere (Rice and Angle 2004).

The global soil C pool is about 2500 Gt and it can be subdivided into 1500 Gt of organic C and 950 Gt of inorganic C. It is 3.3 times the size of atmospheric C and 4.5 times the size of biological C (Lal 2004). The soil organic C pool is highly dynamic and is influenced greatly by management practices, some of which can positively or negatively affect soil quality. CO_2 is emitted from soils by the respiration of plant roots and soil microorganisms. Soil respiration is a major component of the global C cycle. Each year, soil respiration returns nearly 10 times as much CO_2 to the atmosphere as do the emissions from fossil fuel combustion. However, soil respiration is roughly balanced by the net uptake of CO_2 through plant photosynthesis. Globally, net photosynthesis and respiration amount to about 60 Gt C yr^{-1} (Lal 2004).

Located at the plant-soil interface, arbuscular mycorrhizal fungi (AMF) are potentially an important link in the chain response of ecosystems to elevated atmospheric CO_2 (Fitter et al. 2000; Staddon et al. 1999). As obligate symbionts, these fungi depend on the plant as C source (Smith and Read 1997), and thus form an additional C-sink significant enough to enhance carbon fixation under elevated atmospheric CO_2 (Poorter et al. 1996) and to alleviate the photosynthetic down-regulation (Staddon et al. 1999). Therefore, AMF may mitigate the influence of rise of atmospheric CO_2.

3. What are arbuscular mycorrhizal fungi (AMF)?

As indicated before, AMF are an important integral component of the plant-soil system, forming symbiotic associations with most land plants (> 80% of higher plants) and mediating a range of crucial ecosystem processes (Smith and Read 2008). In return for photosynthetically derived carbon, mycorrhizal fungi have a fundamental role in improving plant nutrition, most notably in the provision of phosphorus (P) and nitrogen (N) to the host plant (Smith and Read 2008). In addition, other non-nutritional benefits, such as soil aggregation and stability (Moreno-Espandola et al. 2007), increased drought tolerance (Al-Karaki et al. 2004), and protection against pathogens (Azcon-Aguilar et al. 2002; Gosling et al. 2006) can also be conferred upon the associated host.

AMF exist in two different phases, inside the root and in the soil (Figure 2). The intra-radical mycelium consists of hyphae and other fungal structures, such as arbuscules (sites of nutrient and carbon exchange between the symbionts), and vesicles (sites of lipid storage for the fungus). This phase is connected to the soil mycelium; the extra-radical mycelium forms spores, explores soil and new areas for colonization, and absorbs nutrients (Read and Perez-Moreno 2003). Parameters such as extra-radical mycelium abundance (Miller et al. 1995; Rillig et al. 1999), architecture (Drew et al. 2003), function in nutrient acquisition (Read and Perez- Moreno 2003), persistence (Steinberg and Rillig 2003; Staddon et al. 2003), seasonality (Miller et al. 1995; Kabir et al. 1997; Lutgen et al. 2003), production of biochemical compounds important in the soil (e.g., glomalin; Wright et al. 1996), and interactions in the soil food web (Klironomos and Kendrick 1996) are all considered very important as they influence plant physiology and soil ecological interactions.

4. AMF benefits to crop plants under dry environments

Mycorrhizal associations are the most widespread symbiosis between plants and microorganisms (Marshner 1995) and are found in most natural terrestrial ecosystems including dry environments (Brundrett et al. 1996). Dry areas are characterized by harsh and unfavorable growing conditions, such as low organic matter and nutrient deficiencies in soils coupled with low rainfall and high rates of evaporation. Mycorrhizal association could be helpful for the plant survival and growth under these conditions (Al-Karaki 2010).

In past decades, natural environments were full of mycorrhizae. Healthy soil contains billions of beneficial microorganisms which play a role in nutrition and nutrient recycling. However, over time, and due to application of chemicals (e.g. fertilizers, pesticides), desertification, erosion, drought, compaction, loss of organic matter and

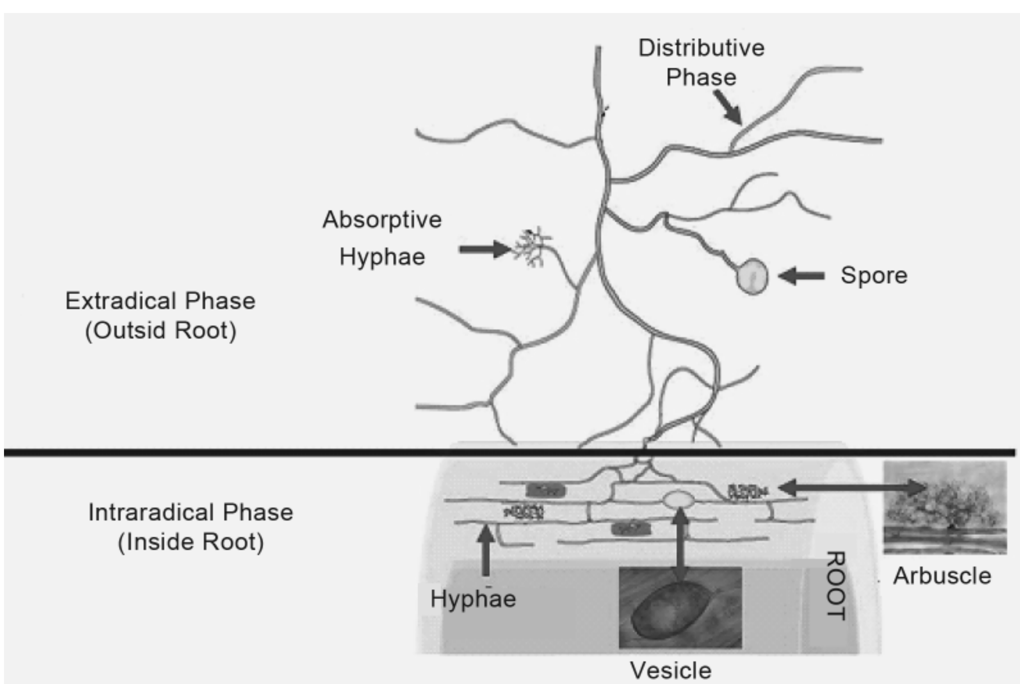

Figure 2. Mycorrhizal fungi exist in two different phases, intraradical (inside root) and extraradical (in soil). Extra-radical part is particularly important in water and nutrients uptake.

other degradation processes, these symbiotic fungi have become less prevalent in soils and the continuous tillage for cropping has greatly reduced the benefits of these fungi in many areas (Mozafar et al. 2000; Oehl et al. 2003).

AMF associations have several advantages for their plant hosts: increased growth and yield (Al-Karaki 2000; Al-Karaki and Hammad 2001), better acquisition of mineral nutrients (Al-Karaki 2006; Stanley et al. 1993) thereby reducing fertilizer requirements (Gemma et al. 1997; Al-Karaki et al. 2007), protection against some root pathogens (Azcon-Aguilar et al. 2002; Govindaraju et al. 2005), improved water relations (Subramanian et al. 1997; Al-Karaki et al. 2004), improved soil structure (Benden and Peterson 2000) and improved tolerance to drought and salinity stresses (Al-Karaki 2000; Barea and Jefrries 1995; Kaya et al. 2009).

A main feature of mycorrhizal symbioses is C flux from the plant to the fungal symbiont, making mycorrhizae an integral link in global C cycling. Transfer of energy-rich C compounds from plant roots to soil microbial populations constitutes a fundamental supply process to the soil ecosystem (Finlay and Söderström 1992). Significant amounts of C flow through mycorrhizal mycelia to different components of the soil ecosystem. The cost of maintaining mycorrhizal associations has been estimated to be between 10-20% of net carbon fixation.

Characteristic mycorrhizal exudates include amino acids, organic acids, sugars and polysaccharides (Read and Perez-Moreno 2003) and can be quickly assimilated by the soil microbial biomass. Additionally, other fungal-specific exudates, such as glomalin (a fungal glycoprotein), are produced by AMF. Glomalin is highly persistent in soil (residence time of four to 62 years) and acts as soil 'glue', which can improve soil structure by enhanced soil aggregation (Rilling 2004; Zhu and Miller 2003).

However, incorporation of recently fixed C into the soil microbial biomass represents only one route for the total diverted C, with a substantial diversion to other fungal structures, particularly to the external mycelial network. Carbon turnover from fine AMF hyphae can be rapid (five to six days) with thicker hyphae taking up to 30 days (Staddon et al. 2003), thus representing an important pathway by which plant-assimilated C enters the soil environment (Godbold et al. 2006). Intraradical vesicles, reproductive spores, arbuscules, and intra and extra-radical hyphae collectively consume a large fraction of C allocated to the fungus. This C pool is likely to have a much longer mean residence time in soil (Olsson and Johnson 2005) than five to six days for the C in the hyphae. Collectively, these data suggest that mycorrhizae contribute to short and long-term soil organic C pools (Zhu and Miller 2003). In terms of C sequestration, long-term belowground storage of plant-fixed C in stable organic forms derived from fungal spores and glomalin offers a means of carbon storage in a relatively stable form.

The stability of macro aggregates in soil is highly dependent on the growth and decomposition of roots and mycorrhizal hyphae. AM fungi appear to be the most important mediator of soil aggregation (Rilling et al. 2000). In AM associations, the external hyphae provide a direct physical link between the host plant and soil resource. External hyphae can bind the small particles into micro aggregates by producing glomalin which alone can account for 30-60% of C in undisturbed soils (Treseder and Allen 2000) and the resultant entanglement of micro aggregates creates macro aggregates that finally lead to improved structure and aggregation stability in soils (Fig. 3) with a wide range of texture (Bearden and Petersen 2002). The resultant increase in soil aggregation, in turn, has important consequences for soil carbon storage (for example, via physical protection of carbon inside of aggregates; Jastrow 1996; Six et al. 2000). Soil organic matter is of great significance in determining or influencing numer-

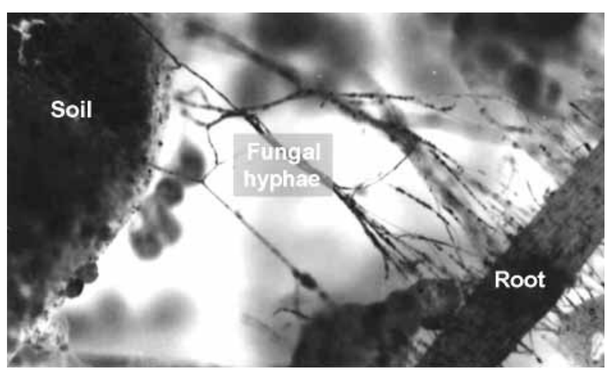

Figure 3. Mycorrhizal fungi filaments (hyphae) that enhance soil aggregation and play an important role in soil carbon storage.

ous aspects of soil quality, including nutrient storage capacity and water-holding capacity (Paul and Clark 1989). Thus, AMF are not only a factor but also key determinants of soil quality.

5. Elevated atmospheric carbon dioxide and mycorrhizae

Over the past decade, a great focus has been placed on the role of AMF in global- change scenarios involving elevated atmospheric CO_2 concentrations (Fitter et al. 2000; Rillig and Allen 1999; Treseder and Allen 2000). AMF can clearly play an important role in the mineral nutrition of their host plant, and this can enhance photosynthesis rate concomitant with elevated CO_2 (Poorter 1993). Elevated CO_2 increases allocation of C to the root system relative to the shoots (Rogers et al. 1996). This could result in more C being available to symbionts in the roots (Díaz et al. 1993). Numerous studies have attempted to demonstrate that this increased below-ground C results in the stimulation of mycorrhizal colonization (Fitter et al. 2000). Under elevated atmospheric CO_2, AMF colonization could be enhanced due to (i) an increased C-availability from the plant and (ii) an increased demand for nutrients by the plant. Consequently, the CO_2 growth response of plants colonized by AMF is expected to be stronger compared to non-mycorrhizal plants (Hartwig et al. 2002). Studies indicated that when CO_2 reached 550 ppm—the level predicted by 2050—hyphae grew three times as long and produced five times as much glomalin as fungi on plants growing with today's ambient level of 360 ppm (Kohlera et al. 2009). In a high CO_2 world, AMF could thus enhance soil C sequestration directly via C allocation to deeper soil and indirectly via enhanced soil aggregate stability through enhanced glomalin production (Rilling et al. 1999).

6. Effects of agricultural practices on mycorrhizae

Large amounts of mineral fertilizers (e.g., N, P) are added annually to the soils in order to enhance establishment of new plantations and to attain high crop yields (Al-Karaki 2002), where much of the P and N may not be taken up and thus large amounts are fixed in the soil due to high pH or escape into the ground water. The trend towards application of organic fertilizers in agriculture/horticulture has increased during the last few years in the arid and semiarid regions as a means of enhancing soil structure and fertility, especially because these soils are low in organic matter. Organic fertilizers are generally compatible with mycorrhizae, whereas phosphorus-rich inorganic fertilizers inhibit the fungi (Amaya-Carpio et al. 2009). P from inorganic fertilizers is directly available to the plant while P from organic fertilizers is made available to plants largely after its mineralization or when hydrolyzed into inorganic P. Mineralization and hydrolysis of organic P is mediated by phosphatase enzyme, activity of which is greatly enhanced in the roots of mycorrhizal plants compared to the nonmycorrhizal ones (Fries et al. 1998; Tawaraya and Saito 1994). Studies also indicated that AMF can have the ability to acquire nitrogen directly from organic sources by both enhancing decomposition of and increasing nitrogen capture from complex organic material in soil. Hyphal growth of AMF was increased in the presence of the organic material, independently of the host plant (Hodge et al. 2001). AMF might therefore be able to substitute for reduced fertilizer inputs in organic systems.

Beyond the benefit of carbon sequestration, mycorrhizal fungi can indirectly bring dramatic reductions in energy use and CO_2 emissions in agricultural systems. Farming systems utilizing mycorrhiza showed reduction in fossil-fuel use due to reduction in chemical fertilizer use (Baar 2008). This would translate into less greenhouse gas emissions. Farming for C capture is also compatible with other environmental and social goals, such as reducing erosion and minimizing impact on native ecosystems. This approach utilizes the natural C cycle to reduce the use of purchased synthetic inputs. Because chemical fertilizers and pesticides are less used, nutrient and chemical pollution in waterways is significantly reduced. Not only would this translate into long-term cleaner waterways, but also reduce environmental cleanup costs.

Agricultural practices such as crop rotation and tillage affect field AMF potential and root colonization levels. For example, growing a non-host plant species (e.g. Canola) delayed mycorrhiza development of next crop (Gavito and Miller 1998). Higher soil infectivity was observed under reduced or no tillage practices (Mozafer et al. 2000). Soil tillage might reduce the rate of colonization of plants by AMF by breaking up the living extra-radical mycelium in the soil (Dodd 2000). The result of this disturbance will be a reduction in propagules of AMF in the soil.

7. Strategies for the management of AMF in soil

Two management options exist: (a) inoculation with selected AMF, and (b) management of indigenous AMF in soil to produce their effective communities. Greenhouse as well as field studies have shown increases in early growth and development of crops when inoculated with effective AMF populations. For example, International Center for Biosaline Agriculture/ UAE, in cooperation with German BioMyc Company, performed a study on inoculating date palm (*Phoenix dactylifera*) seedlings with AMF in soils of varying fertility. An average of a 3-folds increase in plant growth was obtained after 42 weeks over uninoculated seedlings (Fig 4; unpublished data). The benefits of reducing fertilizer inputs (50% less) to optimize conditions for the AMF has been noted for grass lawns in Bahrain where inoculation with AMF increased grass establishment by 2-folds over the uninoculated treatment under filed conditions(Fig. 5; Al-Karaki et al. 2007).

Figure 4. The use of effective commercial inoculum of AMF (German BioMyc™ Vital) increases early growth and development (after 42 weeks) of date palm (*Phoenix dactylifera*) seedlings at the International Center for Biosaline Agriculture, UAE (Unpublished).

The merit of maintaining high levels of both indigenous inoculum and biodiversity of AMF, by adopting appropriate soil management practices over inoculation, has been examined in many studies (Bethlenfalvay and Lindermann1992). For example, pre-cropping, as a cultural practice, with sorghum inoculated with AMF in the previous growing season improved the growth of the subsequent crop (cowpea) compared with uninoculated and uncultivated (control) plots. This was correlated with greater early colonization due to increased native AMF populations surviving the dry season in comparison to that found in the control plots (Dodd et al. 1990).

8. Future outlook

Carbon as CO_2 is currently accumulating in the atmosphere at a rate of 3.5 billion tons y-1 as a consequence of fossil fuel use and land use change. The Intergovernmental Panel on Climate Change Report (IPCC 1995) estimated that soil C sequestration in cropland soils could remove between 40 and 80 billions tons of that C over the current century. This means that soil C sequestration could

Figure 5. The use of effective commercial inoculum AMF (German BioMyc™ Vital) increases early establishment and development of grass lawn at Arabian Gulf University, Bahrain (Al-Karaki et al. 2007).

provide an offset for fossil fuel emissions.

It should be emphasized that mycorrhizal fungi have a crucial role in the global carbon cycle, especially in soil carbon sequestration. Thus, introducing mycorrhizal inoculum into crop plantations is considered a potentially positive intervention in the efforts to reduce the pace of environmental changes. There is currently little information on the input of carbon to the soil via the extra-radical mycorrhizal mycelium. Information is needed to provide land managers and policy makers rates of C sequestration in soils and identify those management practices that enhance C retention.

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Theme 5: Policy Options and Institutional Setups to Ensure Enabling Environments to Cope with Climate Change Impacts

Assessing the impacts of targeting improved crop germplasm on poverty reduction: methods and results

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Abstract

Climate change is expected to increase uncertainties in agricultural production in the dry areas. The deployment of new crop varieties adapted to different environmental conditions is an adaptive strategy that can address the increased temporal and spatial variability. Drought tolerant crop varieties can be used in the drier agro-ecologies thus reducing risk of cop failures; while high potential input-responsive varieties can be deployed in the irrigated environments. However, the success of such a strategy depends on how effective those crop varieties are targeted to their appropriate agro-ecological environments. Seed multiplication and distribution system should be fully equipped to deal with the diverse demands for crop varieties according to different agro-ecologies. Failure to make appropriate seed material available will hamper efforts to reduce climate risks and can increase poverty. This study demonstrates how inadequate targeting of new crop varieties can lead to higher poverty. The results of the study suggest that effective seed multiplication and distribution are necessary conditions for achieving poverty impacts in the dry areas. This requires greater efforts in assessing farmers' demand for seeds of new variety. Climate change will only make this condition more pressing because the dry areas are going to be more affected. Lack of clearer targeting of seeds to the relevant agro-ecologies (recommendation domains) will hamper adaptation to climate change and will lead to failure in achieving expected poverty reduction.

Keywords: agro-ecological targeting, climate change, dry areas, new varieties, poverty reduction, seeds.

1. Introduction

Agricultural technology can be a potent force for the reduction of poverty. Studies have shown that the Green Revolution, which tripled yields of some food grains, reduced poverty by increasing the supply and lowering prices of foods, increasing the demand for agricultural labor, and raising incomes of poor farmers (Lipton and Longhurst 1989; Pinstrup-Andersen 1979). New technologies can lower poverty rates through two broad paths: the direct path, in which incomes rise as the poor farmers adopt the technology; and the indirect path, by lowering food prices, expanding demand for low-skilled workers, and promoting indirect linkages between agricultural production and other revenue generating sectors of the economy (DeJanvry and Sadoulet 2002; Moyo et al. 2006). While the indirect effects always act to reduce poverty, the net contribution to poverty reduction of the direct effect depends on the adoption profile. If poor farmers are late adopters or they face obstacles in adoption, they can be hurt in the short run as increased supplies tend to drive down farm gate prices. Moyo et al. (2006) found that poor farmers in Uganda were late adopters of new peanut technologies and this dampened some of the potential poverty-reducing impacts of the technologies.

Whether the poor are able to benefit from crop improvement technology depends on adoption patterns. However, adoption patterns are affected by the attributes of the technology, such characteristics of producer as age, education, land holding, and wealth, and resources devoted to diffusion (Feder 1980). As the technologies are generally targeted to specific areas and specific agro-ecological conditions, the distribution of poor producers among these areas will affect the degree to which they will be benefitted. For example, the poor might be disproportionately concentrated in low-rainfall areas and technologies developed specifically for such areas may have strong poverty-reducing impacts (Mills 1997). Diffusion efforts can be biased toward or against the poor, depending on policy objectives and the characteristics of the poor. For example, extension services can promote adoption among the poor, as the provision of subsidies for seeds and other inputs.

In cases where governments are directly engaged in seed production and distribution, decisions about which seeds to produce and how to distribute them create a direct linkage between agricultural technology development and its poverty impact. The Syrian wheat market is characterized by strong government intervention in seed development and supply and in the demand side of the market. Since the early 1970s the Syrian Government has used three main instruments to increase wheat productivity: (i) investments in irrigation; (ii) subsidies for input (seed, fuel and fertilizer); and (iii) agricultural research to improve productivity. These interventions complemented each other, boosted wheat production, and helped achieve the food security policy goal.

However, the impacts of wheat germplasm development on poverty reduction in Syria have not been investigated in detail. As rural poverty reduction is an important national and international policy goal, it is critical to understand how substantial public resources devoted to wheat improvement have impacted poverty. The objectives of this paper are to 1) estimate the historical welfare gains and poverty reduction associated with wheat varietal improvement research in northern Syria, 2) identify and analyze obstacles to full distribution of improved seeds, particularly of the varieties developed for irrigated lands and 3) compute the poverty reduction associated with more appropriate multiplication and distribution of improved seeds.

2. Background

The national poverty in Syria is estimated roughly at 30 percent, being generally higher in rural than urban areas. Poverty is greater in the north and north-eastern regions of the country including Idleb, Aleppo, Al Raqqa, Deir Ezzor and Hassake provinces (UNDP 2005; Laithy and Abu-Ismail 2005). Poverty has decreased over the past 10 years in the country as a whole, but has risen in the rural areas of the north-eastern and coastal regions.

In the rural areas of northeast Syria, which is an important wheat producing area, agricultural income represents a relatively large share of total household income. The northern regions account for about 82% of total wheat area, and durum and bread wheat there are produced both on rainfed and irrigated lands. Rain-fed agriculture represents about three-fourths of the cultivated area. Fortunately, poverty in Syria is not too deep, with most poor clustered just below the poverty line. This relative low poverty depth, compared to many other middle-income developing countries, provides a potential to quickly move people out of poverty through pro-poor policies.

Wheat production and marketing in Syria is heavily influenced by the state. The overall policy goal is to increase wheat productivity, enhance national food security, and enhance rural incomes and employment. As mentioned before, since the 1970s, government has used measures such as investments in irrigation, input subsidies and credit, and agricultural research to promote wheat production. Production is controlled through a combination of production quotas and price supports. Government implements an annual production plan that requires certain areas to be allocated for strategic crops, such as wheat, sugar beet and cotton. Although participation in the plan has been recently made voluntary, all farm subsidies are tied to the plan, providing strong incentives to farmers to participate. Wheat prices are announced annually before planting; they are supposed to be high enough to ensure farm profitability. Irrigation is subsidized, and farmers pay only nominal fees for using irrigation networks. Inputs such as fertilizers are supplied with subsidized prices or through cheap credit. The government is the sole buyer of wheat supply and controls all marketing channels.

Over the last 25 years, irrigated wheat area has expanded from 24% to 45% of the planted wheat area nationwide. This expansion of irrigation was much greater in the durum producing areas than those under bread wheat. Irrigation in durum areas increased from just 2% to close to 50%, while

Table 1. The distribution of irrigated (I) and rainfed (RF) durum and bread wheat areas in Syria, 1985-2007.

Period	Bread wheat			Durum wheat			All wheat		
	Total area (1000 ha)	RF (%)	I (%)	Total area (1000 ha)	RF (%)	I (%)	Total area (1000 ha)	RF (%)	I (%)
1985-1990	739	69	31	466	98	2	1,205	80	20
1991-1995	1,223	53	47	840	57	43	2,065	54	46
1996-2000	1,009	59	41	667	62	38	1,677	60	40
2001-2007	954	58	42	810	52	48	1,764	55	45
Surveyed sample	34	49	51	5	30	70	39	47	53

Table 2. Development of irrigated wheat areas in Syria.

Year	Total area	Share of irrigated areas (%)			
	(1000 ha)	NE	North	South	Coastal
1985	2,719	0.24	0.17	0.11	0.06
1995	3,582	0.30	0.15	0.10	0.05
2005	3,537	0.40	0.14	0.09	0.04
2007	3,398	0.41	0.15	0.09	0.05

the share of irrigated bread wheat land increased from 31% to 42% (Table 1). The investment in irrigation was not evenly distributed but was concentrated in the northeast region (Table 2). The irrigation expansion combined with the use of new high yielding varieties has increased wheat production substantially. Irrigation expansion, however, has important implications for the country's crop improvement strategy. Research efforts have to increase to develop varieties that can fully take advantage of the more favorable conditions.

Multiplication and distribution of wheat seed is also controlled by the state through its General Organization for Seed Multiplication (GOSM). Foundation seeds are supplied by the national agricultural research system to GOSM, which then multiplies them through contract farmers for wider distribution. Seeds are distributed by GOSM through offices of the Agricultural Cooperative Bank, which provide seeds and other inputs to farmers through a credit facility. As farmers become aware of new varieties with desirable attributes, they demand seeds of these new varieties. However, farmers produce under different environmental conditions as there is substantial variability within regions in soil type, rainfall levels, access to irrigation and farmers own characteristics. Demand for seed attributes would therefore vary substantially from one farmer to the other, and seed distribution by GOSM should ideally follow this demand.

Breeding programs have produced varieties for different agro-ecologies. For example, 'Cham 6' bread wheat cultivar is appropriate for rainfed conditions while 'Cham 8' is appropriate for irrigated conditions and high rainfall areas. However, ensuring availability of sufficient quantities of seeds of cultivars for each agro-ecology would require a clear understanding of farmers' demand for seeds of different cultivars disaggregated by agro-

Table 3. The attributes of selected modern bread and durum wheat cultivars in Syria.

Variety	Year released	Targeted agro-ecosystem	Potential yields (kg/ha)
Cham 6	1991	Zone 1 (high rainfall, rainfed)	4357
Cham 8	2000	Irrigated (Raqqa)	9058
Cham 5	1994	Zone 2 (low rainfall, Darra, Hama, Edleb, Aleppo)	1847

ecology. The data on adoption of new cultivars and discussions with the officials of GOSM revealed that the process of seed demand assessment for different varieties was not done in a thorough manner. GOSM estimates the quantity of seeds to be produced of each variety in a year based on the average usage in the past 5 years. This estimation may not be accurate if seeds of appropriate variety have not reached their target agro-ecologies in the preceding 5 years. GOSM also uses feedback from contracted seed growers about their preferences as an indicator of general farmers' preference for varieties and their attributes. Contract growers are normally located in more favorable environments or in irrigated areas and do not necessarily reflect demands from farmers in less-favorable areas. As a result, seeds of high yield potential varieties that respond to higher moisture and other production inputs are likely to be produced more than of the varieties that are not that high yielding but more tolerant to drought and superior in performance in dry areas.

According to GOSM the cultivars whose seeds are most in demand are 'Cham 6' and 'Cham 8' of bread wheat and 'Cham 3' of durum wheat, in that order. Multiplication and distribution of seeds of other cultivars have been discontinued due to the lack of demand. It is evident that GOSM's monitoring of demand for seed affects the targeting of varieties to their most appropriate agro-ecosystems. We examined the impacts and potential poverty impacts of seed production and distribution of Cham6 and Cham8 bread wheat and Cham5 durum wheat cultivars. These were released after 1990. The main characteristics of the cultivars are given in Table 3.

3. Methods

We started by examining changes in irrigation coverage and area planted to different wheat varieties in the north-eastern Provinces of Syria (Aleppo, Hassakeh, Idleb and Raqqa). These provinces were targeted because of the high poverty incidence there. We used data of a randomly selected sample of 1010 households (410 households that grew wheat) collected through a survey done in 2007. The survey obtained information on socioeconomic characteristics, assets, income, expenditure, production and crop variety adoption. Household expenditure data covered food and non food items and income data included non-farm sources such as remittances. Farmers were asked about the wheat cultivars they planted in 2005, 2006 and 2007 and area devoted to each variety. The surveyed producers were predominantly smallholders with about one-third (32%) having holdings less than 5 hectares, and about 60% less than 10 hectares. Production and price data were obtained from the Syrian Statistics/ FAO (2009).

We then explored the determinants of adoption of different wheat cultivars using the household data. The purpose of this analysis was to understand the relative importance of individual versus area characteristics in determining the cultivar planted. We used a probit model to estimate the determinants of adoption.

Widely used partial equilibrium impact assessment tools such as economic surplus analysis (see Alston et al. 1995) can be disaggregated by region and by population subgroup to examine the distribution of research impacts. For example, Mills (1997) and Mutangadura and Norton (1999) disaggregated research-induced surplus changes by region and farm type, respectively. However, impacts on household-level and aggregate poverty are not adequately addressed with this method alone because poverty status is household-specific while most surplus measurements are conducted at the market level. For this reason, Moyo et al. (2006), building on a method devised by Alwang and Siegel (2003), suggested using economic surplus analysis to calculate the overall welfare change associated with technology adoption and combining this information with household-level information on well-being and production levels. The household-level information allows the analyst to distribute the surplus among specific producers and consumers. Changes in surplus at the household level can be aggregated using Foster-Greer-Thorbecke (FGT) poverty indices to examine changes in poverty associated with technology adoption. We applied this approach to calculate the poverty impacts of improved agricultural technologies in dry land areas of northeastern Syria.

Economic surplus analysis for adoption of bread and durum wheat varieties provides estimates of changes in prices and in incomes received by producers, but the evidence from the Syrian market is that prices are fixed and unaffected by production levels. The household survey was used to project which households are likely to be technology adopters and to calculate poverty rates in the target areas in northeastern Syria.

We measured adoption of specific cultivars using data from the household survey and combined this information with changes in costs of production and yields associated with adoption of the alternative technologies to calculate household-specific changes in well-being. The projected cost and yield change information were obtained from budget data based on published farm budgets and on the expert opinion about output and input changes that are associated with the technologies.

It was an *expost* analysis, because these technologies have already been released and fully or partially adopted. The household level income changes due to the adoption of these technologies can also be realized through reductions in the prices of specific commodities following the productivity increases. These reductions are calculated in the economic surplus analysis. Household income changes are used in the poverty index formula to estimate changes in the poverty headcount and in the severity of poverty in the region. In brief, estimating the market level agricultural research impacts involved several steps: (i) projecting unit-cost reductions associated with the new technologies, (ii) gathering survey information and projecting the expected level and timing of adoption for each technology by farm-household (with data on the adoption of previous technologies), (iii) combining (i) & (ii) with market-related information on supply and demand elasticities and equilibrium prices and quantities to calculate economic surplus changes associated with technology adoption.

Analysis of predicted changes in poverty resulting from adoption of new technologies then involved: (i) computing the new income per capita by household and comparing it to the poverty line calculated from data in the household survey, and (ii) adding up the number of poor people after the technology adoption and comparing that result to poverty rate before the introduction of the new technology.

4. Results

4.1. Adoption patterns

The ICARDA-CIMMYT wheat germplasm improvement program in collaboration with the Syrian national program has led to the release of a number of improved wheat cultivars; five were released before 1990 and 5 after 1990. A few of them clearly dominate in the area devoted to wheat area in the sample area covered in this study (Table 4). Cham6 (released in 1991) covers about 80% of the bread wheat area, while the relatively older cultivar Cham3 (1987) covers 70% of the durum wheat area. Diffusion of the more recently developed varieties is slow. This lag in technology diffusion has important welfare implications for growers, consumers and the economy at large.

Besides the lag in diffusion, the data showed inadequate targeting of improved cultivars to appropriate agro-ecosystems. The basic breeding strategy to generate improved cultivars for different agro-ecologies is multi-year multi-location trials, where promising ones are compared with existing check cultivars under both less favorable (low rainfall

Table 4. Relative use (%) of different bread and durum wheat varieties in the study area.

Wheat type	Cultivar	2005-2006	2006-2007	2007-2008
Bread wheat	Cham 2	0.7	0.1	0.3
	Cham 4	15.4	10.4	9.1
	Cham 6	79.9	84.9	80.1
	Cham 8	2.8	4.2	9.7
	Others	1.2	0.4	0.8
	Total	100	100	100
Durum wheat	Cham 1	4.8	6.9	4.5
	Cham 3	75.6	70	65.7
	Cham 5	14.4	14.5	21.2
	Others	5.2	8.6	8.6
	Total	100	100	100

Table 5. Cultivation of durum and bread wheat varieties under rainfed and irrigated conditions in study area.

	Cultivar	Total area (ha)	Rainfed (%)	Irrigated (%)
Bread wheat	Cham6	2966	54	46
	Cham8	345	10	90
Durum wheat	Cham5	111	9	91

rainfed) and more favorable (irrigated or high rainfall) conditions. The cultivars showing higher yield performance than existing cultivars under each agro-ecological condition are recommended for that particular condition. While cultivars targeted to rainfed conditions have generally been widely adopted, adoption of improved cultivars targeted for assured moisture supply (irrigated or high rainfall) has not kept pace with growth in the irrigated areas. At the national level, irrigated area currently accounts for 45% of the total wheat area, as against 20% in the past. In the surveyed areas, irrigated area was about 53% of the total wheat area, reflecting a significant investment in irrigation as a measure to boost productivity and incomes. However, the diffusion of cultivars specifically developed for assured moisture supply did not keep pace with the expansion in irrigation in our study area.

Table 5 shows that almost half (46%) of the total land planted with Cham6 was irrigated although it was not developed specifically for irrigated areas. In contrast, the cultivar specifically developed for irrigated conditions (Cham8) covered only small area of the total irrigated land under wheat. However, farmers' preference for growing Cham8 under irrigated conditions is clear as 90% of the area planted with this cultivar is irrigated. This shows that farmers recognize the high potential of this variety under more favorable conditions and the potential for its further diffusion is great. Many farmers with irrigated land who cannot currently get seeds of Cham8 are planting Cham6 that was developed for rainfed conditions. This inadequate targeting of variety to the right environment has significant economic costs. Such costs are delineated in the subsequent sections.

4.2. Determinants of adoption

Three aspects relevant for varietal adoption in this study are level of adoption (or adoption rate), lag in adoption, and appropriate matching of the cultivar and the environment. Assuming that seeds of new cultivar are available, the level of adoption (percent farms or percent area planted) would largely depend on the attributes of the new cultivar and farmers' characteristics. This can be modeled using probit models. But this assumption is generally not valid due to paucity in seed availability. Adoption of new cultivars is therefore heavily influenced by the availability of seeds at the right place at the right time. Hence, seed distribution is a key factor in appropriate deployment of cultivars to the environment. The lag in adoption is mainly determined by institutional and policy factors related to seed multiplication and distribution.

In order to analyze the determinants of adoption of modern wheat cultivars, a probit model was applied to variables that influence technology

Table 6. Estimated parameters of probit function for Cham 6 for farmers planting rainfed bread wheat.

Variables	Estimate	SE	Wald	df	Sig.	95% confidence interval	
						Lower bound	Upper bound
Dummy (Irrigated Cham6=1, otherwise=0)	-0.251	0.583	0.186	1	0.67	-1.4	0.9
Age	0.011	0.008	1.712	1	0.19	0.0	0.0
Total owned land 2007/08 (ha)	0.007	0.006	1.431	1	0.23	0.0	0.0
Machinery owned (number)	0.101	0.067	2.303	1	0.13	0.0	0.2
Distance to market (km)	0.016	3.372	1	0.07	-0.1	0.0	
Dummy road to village (paved road=1, otherwise=0)	0.796	0.316	6.344	1	0.01	0.2	1.4

Table 7. Estimated parameters of probit function for irrigated wheat varieties (Cham5 and Cham8).

Variables	Estimate	SE	Wald	df	Sig.	95% confidence interval	
						Lower bound	Upper bound
(Durum wheat MV adoption=1, otherwise=0)	1.505	0.367	16.854	1	0.000	0.787	2.224
Dummy (Ein El Arab=1, otherwise=0)	2.010	0.366	30.171	1	0.000	1.293	2.727
Dummy (Tel Abiad=1, otherwise=0)	.504	0.274	3.391	1	0.066	-0.032	1.041
Dummy (Tel Tamer=1, otherwise=0)	1.110	0.222	25.021	1	0.000	0.675	1.545
Dummy education (Post Secondary=1, otherwise=0)	0.507	0.375	1.831	1	0.176	-0.227	1.241
Dummy (Irrigated=1, otherwise=0)	0.412	0.202	4.176	1	0.041	0.017	0.807
Dummy (Connected to irrigation network=1, otherwise=0)	0.294	0.294	0.999	1	0.318	-0.283	0.871
Age (years)	0.001	0.007	0.013	1	0.911	-0.012	0.014
Total own land 2007/08 (ha)	-0.003	0.006	0.246	1	0.620	-0.014	0.009
Owned machinery (number)	0.374	0.178	4.406	1	0.036	0.025	0.723

adoption. These include producer characteristics (education and age), farm size, location, access to irrigation, and location in relation to markets and road infrastructure (Tables 6 and 7). Producer's socioeconomic characteristics associated with technology adoption were not found to be significant determinants of adoption, but the region dummies were highly significant. This indicates that under the current structure of seed market, adoption is mainly determined by seed availability, which is affected by GOSM distribution policies, and not necessarily by farmers' choice. As GOSM is the state agency with monopoly on seed multiplication, distribution, it is plausible that farmers use the seeds of cultivars that are offered rather than actively choosing between different offers and making calculated decisions.

4.3. Targeting of varieties to appropriate agro-ecosystem

Earlier (Table 5) it was shown that farmers under irrigated conditions cultivated bread wheat variety Cham 6 (80%), which is appropriate for rainfed conditions while only 10% irrigated area was under the appropriate cultivar Cham 8. Also, as shown in Table 4, Cham 3, a cultivar released in 1987, dominated the area under durum wheat (66%), while the newer cultivar Cham 5 covered only 21% of the durum area. Older cultivars - Cham4 and Cham3 - still cover major wheat areas (Table 4). This highlights two important limitations of the current seed distribution process: 1) there is a lag of over 10 years in the adoption of new cultivars and 2) that cultivars are not targeted to their appropriate agro-ecological conditions. These can result in significant losses to wheat growers and to the national economy as a whole.

The dominance of a few cultivars in wheat production provides an economics of scale for the seed company, but the reliance on a few varieties carries the risk of heavy losses in case of the breakdown of tolerance to diseases and appearance of disease and pest epidemics.

4.4. The economic impact of new wheat cultivars

The economic impact of new what cultivars, specifically Cham6, Cham8 and Cham5, was estimated using the economic surplus models on small open economy and prevailing (2008) wheat prices. The gross annual research benefit of the adoption of durum wheat Cham5 reached US$ 0.1 million in rainfed areas and US$13.6 million in irrigated areas. The gross annual research benefit from the adoption of bread wheat variety (Cham6 and Cham8) was estimated at US$6.5 million in the rainfed areas and US$ 17.0 million in irrigated areas (Table 8).

4.5. Poverty impact

By using poverty estimates of the sample households who are growing wheat with and without the adoption of new varieties, we were able to compute the poverty impacts of the adoption of wheat varieties. The three Foster-Greer-Thorbecke (FTG) poverty measures (head count, and depth and severity of poverty) were computed for the adopters of modern wheat varieties and the non adopters (Table 9). The income poverty reducing effects of the new technology are based on the comparison between the computed income of farmers after technology adoption and what their income would have been if they still used the old wheat varieties. This does not take into account any other thing that these farmers would have done to increase their income in the absence of new wheat varieties. There was a substantial poverty reducing effect of wheat research. This welfare effect was much greater for bread wheat than durum wheat because bread wheat was grown on much larger area than durum wheat. If we combine these poverty reducing effects of wheat research and the slow adoption of more modern wheat varieties due to lack of seeds, we can easily see the huge economic benefit and welfare opportunity being lost due to lag in technology adoption. A new seed multiplication and distribution system that takes into account the diverse demands of seeds by farmers in different agro-ecological environments and makes more careful targeting of seeds would clearly increase the impact of wheat research on poverty reduction.

A clear message from this analysis for the wheat breeding program is that research priorities assigned for the development of cultivars targeted for rainfed vs. irrigated areas was perhaps not congruent with the changing wheat production systems in Syria. It is clear that the cultivars targeted for irrigated areas were developed much later, implying that the potential expansion of irrigation was perhaps not sufficiently taken into account in the breeding program and hence the delay. Another message from this study is that access to crop cultivars that are adapted to different agro-ecologies is one way of adapting to climate change, and both breeding and seed production systems will have to lay more emphasis in making farmers have seeds available of those cultivars that would better adapt to different new environmental conditions that the climate change would generate in order to ensure adequate returns to public investment in research and to enhance and sustain food security.

Table 8. Gross annual research benefits of wheat variety adoption for 2007.

	Net present value of the benefits from technology adoption (US$)	
Type of farmer	Zone 2 (rainfed)	Irrigated
Durum wheat grower	138,636	13,704,395
Bread wheat grower	6,552,455	16,983,666

Table 9. Poverty indicators with and without improved wheat variety adoption.

Crop	**Poverty indices with technology adoption**				**Poverty indices without technology adoption**			
	Head count	**Depth**	**Severity**	**API (US$)**	**Head count**	**Depth**	**Severity**	**API (US$)**
Durum wheat	0.402	0.312	0.286	1.98	0.50	0.443	0.431	1.77
Change %	*24*	*42*	*50*					
Bread wheat	0.394	0.295	0.229	2.37	0.749	0.696	0.65961	1.26
Change %	*90*	*136*	*188*					

API, average per capita income

5. Conclusions

Lack of targeting of seed distribution to appropriate agro-ecologies hinders farmers' abilities to cope with climate change and affect national food security by retarding the productivity growth and food supply. Factors that delay farmers' adoption of new varieties also undermine the efforts in adaptation to climate change and waste research investment. Currently, wheat area is dominated by two varieties which are appropriate for irrigated areas while the majority of wheat is in irrigated areas and hence cannot take full advantage of the inputs while the diffusion of more appropriate varieties is very slow. Clear strategy and action is needed to better target and accelerate the distribution of seeds of new varieties that are appropriate for different agro-ecological zones. One way of doing this is to create the public-private partnership on seed multiplication and distribution with public tackling the quality assurance and producing foundation seeds while the private sector will handle the large scale distribution of seeds based on farmers preferences and demands. Local inputs traders should be encouraged also to sell seeds but with assurances from major suppliers with quality control by the government.

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Food security through community food bank and employment generation: a case study of Kurigram district, Bangladesh

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Abstract

Bangladesh is one of the most populous and least developed nations in the world. About twenty percent people are poor and they face severe food insecurity. Eight districts in the northern part of Bangladesh are more vulnerable to periodic food deficits due to frequent floods and huge river bank erosion in the rainy season and severe drought in the dry period perhaps because of the climate change. In addition, unfavorable agricultural production cycles due to prolonged dry season disfavor intensification of the cropping. Since food deficit is a recurring phenomenon in the study area due to scarcity of jobs in agriculture during the lean period, there is a necessity for creating employment opportunities in non-crop agriculture and agro-processing businesses and off-farm services. Moreover, the provision of physical supply of food and its accumulation in a bank to be managed by the community (community food bank) can be a justifiable approach. Keeping all these issues in consideration, this action research was planned and is being implemented. Training of the target beneficiaries in different trades for employment generation was done. This enabled them to acquire necessary skills, and helped them to choose self-employment in off-farm sectors. In addition, education and advocacy programs were offered to enable them to introduce appropriate technologies in agriculture to boost up their food production with the aim of depositing surplus production in a community food bank (CFB), which could be used during food crisis period. The results showed some positive changes in socio-economic conditions of the target beneficiaries that could be supportive to ensure food security and alleviation of poverty in the face of changing climate.

Keywords: community food bank, food security, self-employment, skill development training.

1. Introduction

Bangladesh is one of the most populous and least developed nations in the world with 153 million (July 2008 est.) people living in a bounded space of 147,570 sq km (www.cia.gov/library/publications/the-world-factbook/print/bg.html). About 20% people are poor and ultra poor and they face severe food insecurity every year (RDRS 2005; Rahman et al. 2008). In addition, nearly 75% of the population is rural, engaged largely in agriculture, and in which women's roles are often unseen and unpaid. More than half of the rural households are functionally landless. Low literacy, high unemployment, extreme poverty, and rampant malnutrition are prevalent among rural people.

Despite significant economic and social progress made over the past 25 years in Bangladesh, a large section of the population suffers from serious food insecurity. Although the food grain production has increased steadily with an average growth rate of 3.1%, doubling the production since 1972 (BBS 2007), the national production is insufficient to meet the demand. The deficit is met by import of food grains and food aid.

Although poverty has been declining at the rate of 1% per year, the number of poor/ultra-poor people is increasing due to rising population. Some 25 million Bangladeshis consume less than 1,800 Kcal/person/day, falling in the poverty category (RDRS 2005). It is also expected that the population may double, from 153 million now, in the next 25 years. It is predicted that the vulnerability of the people of Bangladesh would further increase due to the impact of climate change on all forms of agricultural production in the country. Therefore, there is an urgent need to address the issue of sustainable livelihoods and food security from the national to household levels even though the country is on the verge of achieving self-sufficiency in food grain production.

The Roumari Upazila of Kurigram district, situated in the north-eastern part of Bangladesh along both the sides of the Brahmaputra-Jamuna River and its tributaries is one of the very high food-insecure *upazilas* (sub-districts) in Bangladesh (RDRS 2005; BBS 2007). The inhabitants living in this region become regular victim of frequent floods, occasional droughts and persistent river bank erosion (Islam 2006). Unfavorable agricultural production cycles and reorientation of land ownership due to regular river-bank erosion that multiples new landless farmers, worsens the situations of tenants-landowners relationship and ultimately disfavours the higher cropping intensity, resulting in a near-famine situation, locally called *Monga*. Besides, the poorest of the poor are somewhat bypassed by any development efforts because of their remote location from the main land. Apart from income poverty, high malnutrition, poor health, poor education, high infant and mother mortality rates are common amongst the poor in this area. Therefore, the area deserves immediate attention for employment generation and supply of food during the crisis period. Since food deficit is a recurring phenomenon in the area due to scarcity of jobs in agriculture during the lean period and the local economy is based on traditional crop-based agriculture, there is a necessity for creating jobs in non-crop agriculture and agro-processing businesses and off-farm services. Moreover, creation of a food bank to be managed by the community can be a justifiable approach to ensure food security during the periods of crisis. This approach may be able to lessen the pressure on the vulnerable people from the food aid programs that often undermine the human potentiality, dignity and self-reliance in the long run.

Advocacy and motivation programmes for self-help may perhaps boost their confidence, inspire them to engage in creative efforts, shake off negative socio-cultural inhibitions, help them take rational decisions, and finally make them aware of socio-economic opportunities and challenges. Training and skill development component will equip them with needed technological know-how, provide knowledge of marketing and management practices and thereby expand the set of their choices.

The above stated background persuaded the two academic institutions (Jahangirnagar University, Bangladesh and University of Hull, England) to develop an effective and closer functional partnership with a non-government research organization (Unnayan Uddog, a Bangladeshi NGO) to do action research, and to develop an integrated activity model for food security through community food bank and employment generation. It is expected that successful implementation of this action research may help guide the development of academic curriculum for educational institutions; and assist in the transfer of field experience on food security and community food banks to different stakeholders through academic exchange programs, certificate courses, professional training, skill development training, etc. It is also believed that these approaches would bring positive changes in the society and may be focused at the national levels in eradicating poverty and ensuring food security in crisis-prone areas in Bangladesh.

2. Location of the study area

The study area lies between 25º30′ and 25º40′ North latitudes and 89º46′ and 89º52′ East longitudes (Figure 1). This mainly barland area is geographically and economically detached from the main land, often inaccessible. Thus, administrative services are naturally insufficient. Besides, prospects for diversified agriculture are also bleak although rapid socio-economic upliftment of the region is urgently needed.

3. Objectives

The main purpose of the action research is to increase the self-employment opportunities of the poor/marginal farmers by conducting skill development training program that may enable them to acquire necessary skills through hands-on-training, helping them to choose self-employment in off-farm sectors. In addition, education and advocacy programs would be offered to the poor/marginal farmers to introduce appropriate technologies in agriculture to boost up their food production aiming to raise the income.

Another important purpose of this research work is to design relevant courses/training modules on food security and community food bank to disseminate lessons learned to researchers, research students, academic and administrative staff, and field support staff. The themes of the courses/modules are thought to be of long term significance and therefore could be sustained for a long

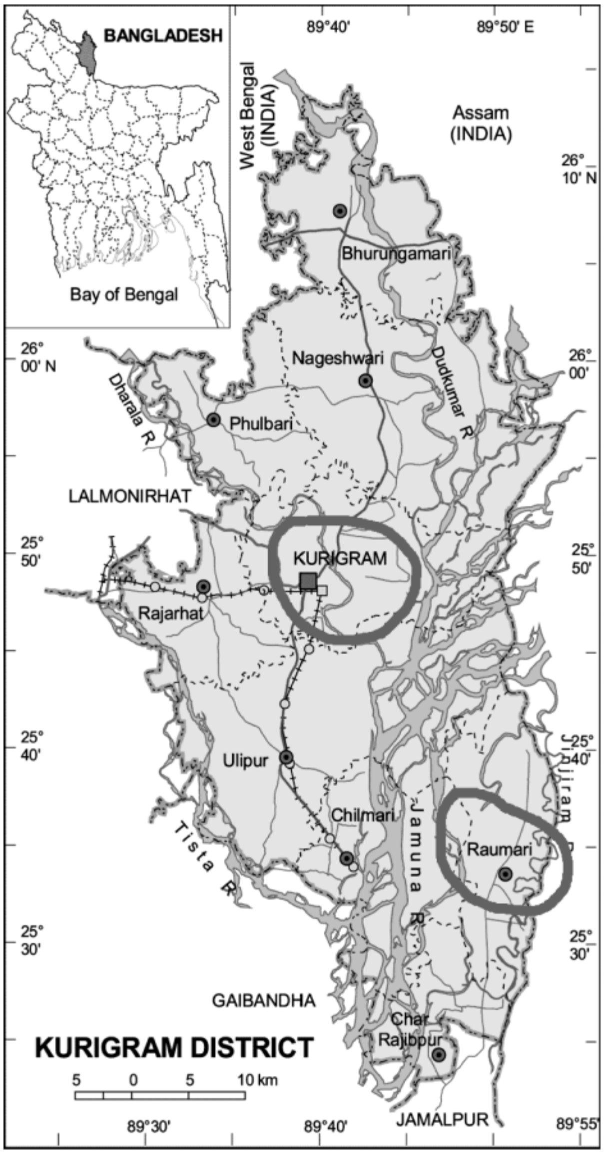

Figure 1. Location of the study area.

period. The students/participants would be trained to develop key skills and adopt proactive attitudes through participation in interactive lectures and practical activities. After completion of the academic courses/training modules, participants would be encouraged to share and transfer their knowledge to primary stakeholders and to build up awareness on food security and community food bank. The students would be encouraged to go to the study area to gather key information from the affected people which would help in further development of the programs.

The long term goal of the research work is to achieve the food security of the *Monga* affected people in the northern region of Bangladesh by increasing the agricultural production and diversification of occupation in off-farm sectors. It is also hoped that demonstration and replication of the result in other areas of Bangladesh would contribute to achieving the millennium development goal for food security in the country.

4. Target group

The regular victims of *Monga* were considered as the target group. The group includes landless and the asset-less daily wage workers and divorced/ deprived women, widows and orphans, plus the small and marginal deficit farmers (owning less than 0.5 acre of land) who were identified through a baseline survey in the target area. Initially, 550 households from two study villages (Khanjanmara and Baguarchar) were surveyed to select 50 households, of whom more than two-thirds are women, because, they are more vulnerable to *Monga* and less preferred community for employment.

5. Components of the research work

To achieve the goals and objectives, this action research work was formulated and operated with an integrated approach that includes the following four components:

Component 1: It involves advocacy and skill development training to the members of the target group for their self-employment. Currently, programs are offered in four trades: i) *Nakshi kantha* (quilt embroidery), ii) bamboo and cane products iii) paraffin candle, and iv) mushroom cultivation. In addition, education and advocacy programmes are regularly offered to the target groups to introduce appropriate technologies in agriculture to boost up their food production. This component also aims at encouraging the introduction of relevant courses at undergraduate, graduate and postgraduate levels by the academic institutions.

Component 2: Setting up an outlet in Dhaka city to sell the products made by the target groups. This is important as the small producers are not getting the fair prices because they have no direct marketing mechanism. It would be a kind of a cooperative shop managed by the NGO that will replace the intermediaries in marketing farmers' products and ensure that a greater part of profit will go to the beneficiaries and the rest used to meet the running cost of the outlet.

Component 3: Establishment of a community food bank (CFB) to provide food during seasonal deficits in the lean months (mid-September to mid-November) of the year or during the disaster period. The CFB will keep deposit of the surplus food from the beneficiaries and give it back to them during the crisis period. Food entitlement of the poor would be ensured partly through eased supply due to additional food produced and partly through higher incomes from new employment and from the benefits of community cooperatives.

Component 4: Provision of micro-credit for supporting small trade, buying of inputs for non-crop agriculture, processing and many other income-augmenting activities that the borrowers would like to pursue. This would enable the target people to make use of their newly acquired skill by engaging in suitable trades/jobs of their choice.

6. Dissemination of the outputs and outcome

Agriculture is the backbone of Bangladesh's economy. The government intends to make this sector a commercially profitable one and is therefore taking several measures to develop agro-business and agro-industries in the country. Development partners are also taking up schemes to diversify agricultural production. Therefore, a better understanding of food security and community food bank will help in designing policies.

The knowledge generated on poverty alleviation through community food bank and employment generation will be shared and disseminated through community workshops and advocacy programs for the beneficiaries; roundtable meetings with senior academics and administrators; seminar/workshops at national and regional levels; academic exchange programs between higher educational institutions; national/international publications; and hosting a project website for global community.

7. Methodology

Both qualitative and quantitative information have been collected from household surveys. Key informant interviews, focus group discussion, and community workshops have also been conducted. Questionnaire surveys were carried out in the selected two villages of the study area. Some 550 households that own less than 0.5 acre of land were chosen for questionnaire survey.

Data have also been collected from different government and non-government organizations. Several people from different government departments, educational institutions, and local NGOs involved in poverty alleviation programmes were interviewed to gather information on extent and trends of hunger and food security in the project site. Collected data has been assembled and analyzed using SPSS and Microsoft Office Excel programs.

8. Key findings

As the objective of the action research is to achieve the food security of the poorest section (particularly the *Monga* affected people) through employment generation, the landless and functionally landless people are included as target groups (TG). During the baseline survey, 550 people were randomly selected from the two study villages as target beneficiaries of the project. However, out of these 550 people only 50 were selected as the target group in the first year of the project and rest are treated as control group (CG) who will be

Table 1. Basic demographic profile of the target group.

Indicator	**Bangladesh (National Average)**	**Study area**	**Target group**
Percent landless	15.62	7.6	31.8
Percent functionally landless	-	66.2	100.0
Average size of land (decimal)	-	63.6	4.7
Ownership of agri. land (dwelling)	55.58	46.7	0
Family size	4.9	4.7	4.6
Literacy % (for 5+ year old population)	43.28	27.1	42.35

Table 2. Comparison of average family expenditure (Bangladeshi Taka, BDT) between the baseline and impact survey.

Survey period	Expenditure (BDT)
All households in baseline survey	691.07
Target group in impact survey	623.18
Control group in impact survey	450.10

Table 3. Comparison of average family expenditure (BDT) between the target group (TG) and control group (CG).

Duration	TG	CG
Before joining	534.45	620.85
One year after joining	623.18	450.10

Table 4. Trade wise income by the target group (TG) during the last six months.

Trade	No. of people in TG	Average earning (in BDT)
Bamboo & cane work	8	6560.00
Mushroom cultivation	15	3420.00
Paraffin candle making	7	6210.00
Nakshi Kantha	20	4150.00
Total	**50**	**4455.90**

included in the later phases. During the selection of target group, female headed households were given preference because they are the oppressed class in the society.

Field survey showed that 32% target group households are landless (Table 1). Average size of the land of the TG households is 4.7 decimal (100 decimal = 1 Acre).

Since the inception of this food security and employment generation project, continuous orientation, advocacy programs and skills development training have been giving to the target group, to raise their consciousness to self-respect and self-dignity and to ignite their desire to reduce poverty through their own efforts. The aim of the skill development training is to create the opportunity for the people to start economic activities. The skill development training and advocacy programmes are continual processes because these will enable the target group to increase their income substantially. At present, based on early impact assessment, the income of the TG did not rise markedly but they are earning regularly and their economic capacity has slightly increased (Tables 2 and 3). They expend more money in comparison to the control group. On the other hand, the capacity of the control group has declined.

Table 4 shows the income earned by the TG members during the last six months of the first year of the project. Each member earned about Bangladeshi Taka (BDT) 4456 on an average by that time. It is hoped that the income level would increase from the next year.

During the impact assessment survey, the members of the target group were asked whether the ongoing training program can be helpful to earn better livelihood or it can be helpful to eradicate/reduce *Monga* from the locality. All of the members of the TG respondents replied positively. They also pointed out some other trades that would have income generating prospect in the locality for introduction: jute work (31.8%), livestock production (27.3%), tailoring (27.3%), small businesses (6.8%), vegetable production (4.5%), and others (2.3%).

The TG respondents showed their positive attitude regarding the prospect of the on-going program that has created opportunities of self-employment (Table 5) and 97.3 % felt it would be helpful in

Table 5. Impact of CFB programme in creating self-employment opportunity.

Response of the TG	**%**
Training creates self employment opportunity	68.2
Activities help to eradicate poverty	13.6
Created jobs and getting benefits	11.4
Meet up family expenditure partly	6.8
Total	**100**

achieving food security in the locality. All of them thought this project would be able to influence others to take similar efforts to remove Monga from the locality.

Some social changes have been made in the life of the target group by the establishment of the community food bank and the start of the employment generation programs. For example, 96% TG respondents said that they got positive reactions from their family members on their joining the project. All those TG members who had pluralise spouse acknowledged that the spouse gave more respect because of the increase in earnings for the family (75.7%) or because they were getting income generating training (24.3%).

Their current earning is small but regular, and their families understand that if they continue their activities their earning will gradually increase.

The majority (95.5%) of the TG members said they were also getting more respect from their pluralise neighbor because they are involved in earning pluralise process that help their families. Similarly, rich or influential people of the society did not discourage them from joining such a program, and pluralise two-third of the TG members reported that the poor pluralise neighbor also encouraged them, although one-third said such neighbors discouraged them because their earning was not sufficient.

Although it is a very short period to assess the impact of the project and to change the attitude of this section of people but some changes are noticeable in the mind set of the people of locality. The target group/beneficiaries are hopeful that the project would be helpful in eradicating the *Monga* from the region if it involved all the people like them.

9. Concluding remarks

Bangladesh is facing serious food-insecurity with its big population and over-exploited agricultural land that is decreasing at an alarming rate due to unplanned industrialization and urbanization. Moreover, it is well documented that agricultural production will be adversely affected by climate change, the livelihoods of large numbers of the rural poor will be put at risk and their vulnerability to food insecurity would increase. As compared to other parts of the country, food deficit is a recurring phenomenon in the northern regions of Bangladesh (*Monga* affected districts) due to scarcity of jobs in agriculture during the lean period as the local economy is mainly based on traditional crop husbandry. Therefore, there is a need for creating jobs in non-crop agriculture and agro-processing businesses and off-farm services. Merely focusing on narrow agro-production, the problems of the daily labourers, landless poor and marginal farmers cannot be addressed effectively. Self employment in different small trades together with micro-credit for income-earning pursuits may improve incomes of the poor, and also create part-time jobs for the small and marginal farmers. The action research project outlined above aims at providing training to the target group in the income generating activities and creating an outlet for a fair trade of their products to contribute to poverty alleviation. It also aims at ensuring food security through establishing a community food bank. There are already positive impacts visible on the target group of the activities and general positive responses of the society in the study area. It is hoped that, by the end of the project, new pluralise door may open for changing the policy, behavior and attitudes regarding the existing development paradigm. There are good chances for the spread-out and spill-over effects of the project in and around this sub-region of Bangladesh by attracting the attention of other stakeholders in the area such as other NGOs, and social and financial institutions.

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Drought mitigation in Salamieh district: Technological options and challenges for sustainable development

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Abstract

Syria is a semi-arid country prone to water shortage, due in part to low levels of precipitation and inefficient management of water supplies. Periodic droughts exacerbate the problem of water shortage and place greater risks on livelihoods. One of the areas affected is Salamieh district located in central Syria, which relies mainly on groundwater for irrigation. The Aga Khan Foundation has promoted a number of mitigation strategies through a multi input area development approach. Three are specifically discussed in this paper: (i) increasing the efficiency and productivity of irrigation water through adoption of modernized irrigation and groundwater monitoring; (ii) facilitation of access to new drought tolerant barley cultivars, and (iii) raising awareness on new and improved feeding techniques in conjunction with new forage cultivars to improve livestock productivity and animal health. Through farmer-farmer transfer of new technologies and facilitating access to group loans, there has been notable success in terms of high adoption of modernized irrigation technologies and new drought tolerant barley cultivars, leading to higher economic returns and lower risk. Despite positive gains, there still remains concern over whether improvements in water productivity are offset by policies and choices that increase water depletion.

Keywords: drought tolerant seed adoption, feed techniques, groundwater monitoring, modernized irrigation.

1. Introduction

Syria is considered a semi arid country and faces a growing problem of water shortage, a consequence of limited water resources coupled with an increased demand and inefficient water management. This is likely to be worsened by the effects of long term climate change, which in dry areas is expected to contribute to an increase in drought years and further declines in precipitation. The likelihood is that both precipitation changes combined with climate-change induced temperature rise will also increase the water requirements of crops (Nelson et al. 2009). Thus, the urgency of providing supportive development programs that address the issue of agricultural sustainability, whilst contributing to food security and climate-change adaption has been well documented (Nelson et al. 2009).

Recognizing the link between poverty and natural resource endowments, one manner in which The Aga Khan Foundation (AKF) is striving to improve livelihoods is by encouraging beneficiaries to utilize existing resources more efficiently without placing undue pressure on the natural environment. Since 2003, AKF has worked with agriculturally reliant communities in Salamieh district (Figure 1) to tackle a persistent problem of irregular rainfall patterns and consequent water shortages.

The Salamieh district is situated in the centre of Syria and covers approximately 5000 sq km with an estimated population of 241,000. It falls among the Syrian agro-climatic Zone 2 (average rainfall 300mm) and Zone 4 to (average rainfall <200mm).

It is characterized by low and erratic rainfall which is typically distributed unevenly over the growing season. The majority of the arable cultivable land is rainfed (100,174 hectares) and the remainder, approximately 9,225 hectares, is irrigated (MARR 2007). There is a heavy reliance on full irrigation during the summer for the production of summer vegetables and supplemental irrigation is widely used on winter crops (mainly wheat and barley) as a method to improve and stabilize yields during the winter growing period.

Overall irrigated farm land has decreased from 40,000 hectares in 1960 to approximately 9,000

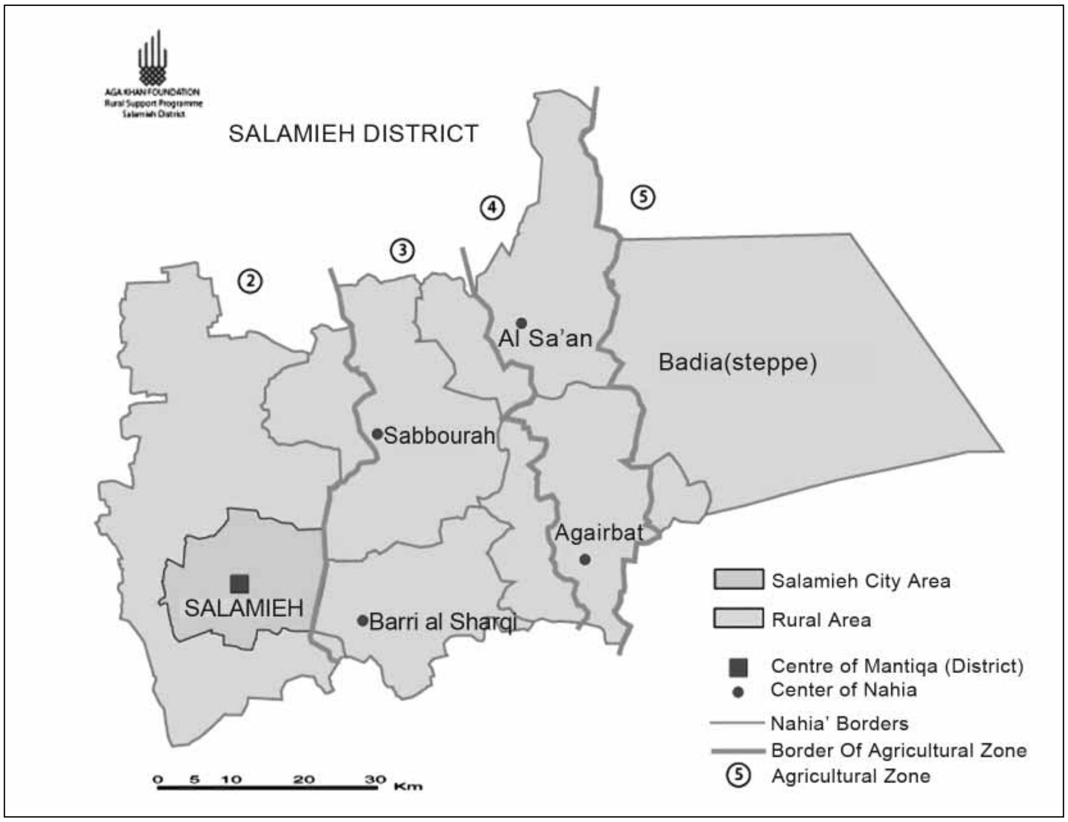

Figure 1. Salamieh district in relation to the administrative and agricultural zones of Syria.

hectares in 2007. This has largely been due to a previous concentration on water intensive cotton production which started in the 1960's, and resulted in a decrease of functional wells. Of the approximate 6000 groundwater wells identified by AKF in 2003, almost 3,500 were dry. Moreover, despite legislation being introduced to prohibit the digging of new wells the number of wells has continued to rise (see Figure 2).

Of the arable (cultivable) land within the district, approximately 79% is planted under cereal crops

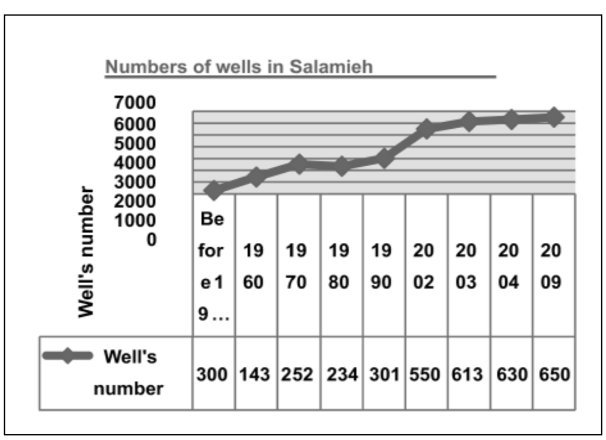

Figure 2. Number of wells in Salamieh district by year.

and of this percentage, 80% is planted under barley and rotated with barley, left fallow or in some cases rotated with leguminous crops. On irrigated land barley in zones 2 and 3 is rotated with summer vegetables. Quite apart from human consumption needs, barley, along with leguminous crops, provide important inputs into livestock production, a significant source of income for many rural households in Salamieh District. The choice of barley over other cereal crops is also of further strategic importance to Salamieh given that barley consumes 50% of the water required for wheat production.

In 2008, Syria experienced a severe drought with the lowest annual rainfall in more than four decades (FAO 2009). This caused acute water and food shortages and impacted heavily on the health and nutritional status of many communities. Farmers dependent on rainfed agriculture have been particularly affected with many experiencing very minimal or no yields from their rainfed lands. Similarly, the onset of high animal feed costs and reduced productivity of grazing lands have caused a significant overall reduction in feed availability throughout Syria resulting in an increase in animal mortality and a drop in fertility (FAO 2009.

Within Salamieh district, a 40% loss in livestock occurred as a result of the severe drought in 2008 (AAS 2009).

Whilst this paper deals solely with agricultural responses to drought mitigation, it should be noted that other areas are equally interconnected and affected by drought specifically extended periods of drought years i.e. 'hydrological drought'. Moreover mitigation strategies should also reflect the increasingly human impact that drought has not only through food and nutrition insecurity, but also by causing migration of households, in search for work or food, reducing school attendance for children, and exacerbating certain health risks. This is often referred to as 'socio-economic' drought and highlights one example of why a multi-input approach to drought mitigation is needed and one which takes a long-term view on sustaining livelihoods. Use of sustainable livelihoods framework to assess a community's resilience to climate change, therefore, becomes important (Eklasha et al.2005).

However, for the purpose of this paper three mitigation strategies that directly relate to the agricultural drought episodes are discussed: (i) increasing the efficiency and productivity of irrigation water through adoption of modernized irrigation and groundwater monitoring; (ii) facilitation of access to new drought tolerant barley cultivars and (iii) raising awareness on new and improved feeding techniques in conjunction with new forage cultivars to improve livestock productivity and animal health. The paper aims to highlight some of the successes and lessons learnt under each of the themes mentioned above using data gathered from AKF surveys and periodic evaluations. It also aims to put each of these mitigation strategies within a broader policy context.

2. Improving irrigation water efficiency and groundwater monitoring

2.1. Improving irrigation efficiency

Since 2003, AKF has concentrated its efforts on improving the productivity and efficiency of water used for agriculture, through increasing the adoption of modernized irrigation pluralise systems (mainly drip irrigation systems). The level of irrigation efficiency for a sprinkler, drip system or pressurised irrigation technique is estimated to be between 80-94% where as it is much lower (35-40%) for traditional gravity (surface) irrigation largely due to evaporation and seepage (Hamdan et al. 2006).

The first phase of the project targeted summer vegetables and fruit tree producers as the water requirement of these crops is more than double that of the winter crops. To date, AKF has assisted over 900 summer vegetable growers to install drip irrigation systems. This has helped to speed up the government's initiative of increasing uptake of modernized irrigation started in 2006. In spite of the provision by the government of interest fee loan to farmers and grants that cover 30-40% of the cost of the networks, the uptake had been slow. The constraints over adoption as mentioned by de Chatel (2009) are: (a) The individual costs to farmers are still very high; (b) Many farmers are unable to acquire the low interest loans and grants from the government as it requires proof of land ownership, which has become problematic owing to issues around the current land cadastral system; (c) As agricultural water is not priced there is a lack of incentive to reduce water consumption and invest in costly techniques; and (d) Most adopters lack the information on proper installation and maintenance of such systems which results in inefficiency and increases the costs in the long run for the farmer.

The focus thus far by the AKF has squarely been upon behavioral change, providing affordable and easily accessible loans (group/individual) and the provision of on-farm technical support. Furthermore, the AKF has helped to facilitate: (a) Reduction in equipment costs (negotiated with the supplier due to the large purchase from a group); (b) Small and manageable loans which do not require "collateral"; and (c) Technical support in designing, installing and operation/ maintenance of the irrigation networks.

Some 90% of the land used for summer vegetables and fruit trees in Salamieh District is under modernized irrigation (Table 1). With the first phase target of 95% land coverage of summer vegetables and fruit trees nearing completion, emphasis has switched to phase two of the project, that would promote similar system for supplemental irrigation of the winter season crops, which are currently irrigated by surface irrigation. Due to the 'occasional' use of the systems during the winter growing season the high capital investment cost often reduces uptake. Additionally, rainfed crops are cultivated on a large amount of land and therefore would require a large irrigation system (Oweis 1997).

In a small sample of farmers surveyed, farmers adopting drip irrigation for winter wheat used 24% less water per unit area than farmers utilizing traditional surface irrigation. In terms of productivity, drip irrigation also allowed an average 40% increase in yields per hectare relative to surface irrigation production (Table 2).

The average yields of new wheat cultivars were 3.1 tonnes (311 kg/dunum) higher than under surface irrigation. Average production was valued at $1750 with profits of $1150 allowing the farmers to fully payoff a loan averaging $835 plus $70 in interest in one season and still have $250 cash on hand. The drip irrigation equipment, is expected to last for a further 4-9 years. Nine out of ten farmers surveyed were able to pay back the loan in the first season. Results were, however, not as promising when old wheat cultivar was grown. The likely benefit for such drip users over surface irrigation is only the reduction in overall water application per unit of area (Table 3).

When analyzing the water productivity (WP= yield/average amount of water applied) and on-farm water efficiency [FWUE = (water required/ water applied)(100)]. Similar overall benefits of the drip system are evident (Table 4).

WP for grain was 61% higher with drip than under surface irrigation. Moreover, straw produced under drip was more than double (124% higher) that under surface irrigation. The FWUE, which gives an indication of how well water is used in relation to its requirements (Shideed et al. 2005), was almost 9% more with drip than surface irrigation.

As less water is applied per unit of land under drip irrigation, some farmers have used the water saving to increase the area devoted to summer vegetable production. Thus, although there are many positive spin-offs including higher yield

Table 1. Modernized irrigation target by land area, period and type for Salamieh district.

Period	Cropping	Area (ha)*	Direct coverage		Overall target (%)	Achieved (%)
2003-2010	Summer vegetables and fruit trees	4569	1350	30	95	90
2008-2013	Winter crops	4656	200	4	50	10

*These are estimates are based on the total irrigated land figures retrieved from MAAR

Table 2. Average yields (kg/dunum) of new and old cultivars of winter wheat under surface and drip irrigation system by different number (No.) of farmers.

Cultivars	Surface irrigation		Drip irrigation		Difference (drip - surface)
	No.	Yield	No.	Yield	
All	13	537.69	10	753.90	216.21*
New	6	541.67	7	853.14	311.47*
Old	7	534.29	3	522.33	-11.96

* significant at the 0.05 level ; N= number of farmers

Table 3. Water applied (m^3/dunum) under surface and drip irrigation system for new and old cultivars of winter wheat by different number (No.) of farmers.

Cultivars	Surface irrigation		Drip irrigation		Difference (drip - surface)
	No.	Yield	No.	Yield	
All	13	601.35	10	487.10	-114.25
New	6	530.41	7	494.41	-36
Old	7	662.14	3	469.00	-193.14

Table 4. Grain and straw water productivity (WP) and on-farm water use efficiency (FWUE) per dunum.

Irrigation method	WP grain (kg/m^3)*	WP straw (kg/m3)*	FWUE**(%)	Water applied (including rainfall)*
Surface	0.59	0.42	67	901.35
Drip	0.95	0.94	76	787.10

* All calculations include average rainfall equivalent to 300 cubic meters per dunum
** FWUE is calculated based on a water requirement of wheat of 600 cubic meters per dunum or 600mm based on prevailing norms

and lower water use per unit area, the long-term sustainability of the availability of water at a basin level may be in question. For example, as farmers take advantage of the higher productivity per unit of area of land by bringing new areas into cultivation this may not necessarily save water at a basin level as the total volume of irrigation water used may increase (Ward and Velazquez 2008).

Additionally, the higher prices of wheat may induce more farmers to grow wheat and thereby use more water. Oweis and Hachum (2009) have recently shown that higher product prices and lower irrigation costs encourage the use of more water. They further noted that policies that support such high prices and low cost of irrigation would encourage farmers to maximize yields rather at lower water productivity. This said, increasing the water productivity through drip irrigation for wheat may well lead to increases in wheat production over other crops such as some summer crops which have lower water productivity.

2.2. Groundwater monitoring

Within its focus on improving irrigation water efficiency, AKF is attempting to increase the awareness among farmers about depleting ground water, given irregular recharge rates and consistent pumping of groundwater for irrigation purposes. Some 120 wells across 120 villages are currently being monitored quarterly by AKF. A move towards a more focussed programme of basin wide accounting of water usage and understanding of hydrological patterns is critical in this regard as are measures aimed at reducing groundwater extraction.

In recent years, the reduction in the subsidy on fuel prices has caused a dramatic increase in the pumping cost for irrigation water. Although it is argued that the reduction of such subsidies may adversely affect farmers' welfare by lowering incomes, particularly that of poorer farmers, Lingard (2002) suggests that the reduction or removal of such a subsidy will increase economic efficiency, reduce government spending and also improve environmental quality. Furthermore, farmers' incomes and profitability will eventually recover following an initial adjustment period (Lingard 2002).

If such policy decisions are implemented, this may curtail the amount of overall irrigation water use and induce farmers to alter their cropping pattern in order to allocate water more efficiently i.e. to those crops that are less water intensive. Gul (2005) showed in several fuel-cost scenarios for five villages in four stability zones in Aleppo (Syria) that agricultural policies that sustained low irrigation costs resulted in farmers over-irrigating largely due to both high intensity of well drilling and expanding their land under irrigation. However, as availability of water grew scarcer farmers reduced the area for high water consuming crops because of the increase in production costs.

Table 5 Difference in depth of the water table for selected villages with low and high adoption of modernized irrigation, 2007/2008.

Adoption group	Mean change in depth (m)	SD	Number of villages	Difference from the general mean (m)
Low adoption (≤66%)	-3.60	2.39	8	-0.92
High adoption (>66%)	-2.00	2.00	11	0.67
General mean	-2.67			

The reduction in subsidised inputs has helped to increase the rate of adoption of modernised irrigation by increasing the value of irrigation water; it may not have an effect on overall water use in areas where water availability is high. However, in an area where water availability is likely to decline does the increase in irrigation efficiency and possible growth in land under irrigation (i.e. overall water use increasing) compromise availability of this natural resource for future generations? For these reasons, it is also very difficult to gauge whether such water saving technologies have had any impact at the basin level.

Figure 3 shows the change in water table depth across 23 villages in Salamieh district from 2005 to 2008. It is an important indicator of the water balance/availability within an area. The balance is positive when the amount of water consumed in irrigation is less than the amount recharged. Values above 0 on the graph indicate a positive overall difference and positive water table and those under 0 signal a negative difference and overall negative water table.

The overall trend over 2005/2006 and 2006/2007 for a number of villages was positive. However, from the period 2006/2007 to 2007/2008 almost all the villages had a negative balance (reduction in the water table) because of the lack of recharge in 2007/2008, which was a drought year. Despite this and using a drought year as an example where a negative water table is found in almost all villages, a 'crude' proxy indicator for the success of mass modernized irrigation adoption is shown in Figure 4 in which the percentage of land under drip irrigation for summer crops and fruit trees for each village is plotted against the difference in water table depth in 2007/08. A high concentration of villages that have a higher percentage of land under modernized irrigation with a lower difference in the water table is evident.

Table 5 shows the mean difference in water table depth in 2007/2008 for the group of villages with low and high level of adoption of modernized irrigation. The mean change in water table depth was -3.6 meters with low adopters as against -2 meters with the high adopters. The higher SD value shows that there was a high variability within the low adoption group. The means were statistically ($p>0.05$) not different. A larger sample size and time period would be necessary to get more precise information.

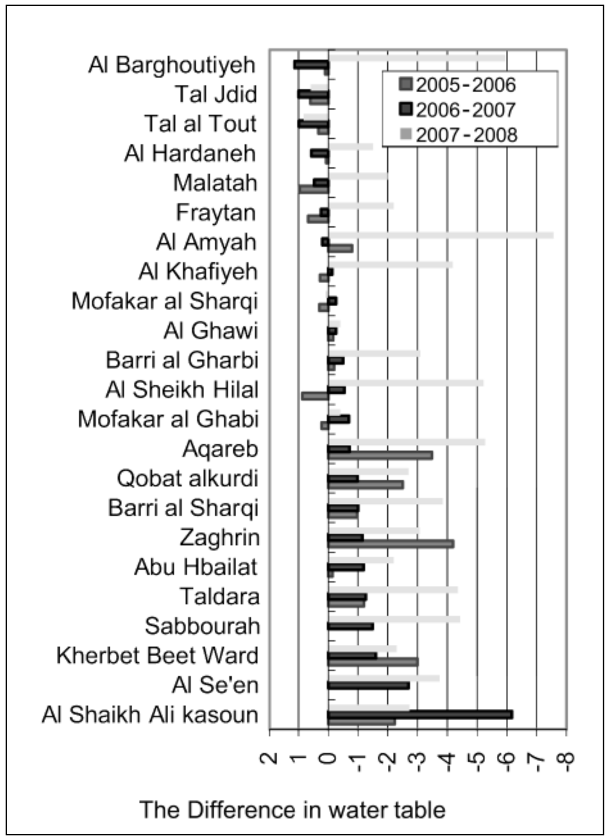

Figure 3. Difference in water table depth, 2005-2008, for 23 villages in Salamieh district.

3. Drought tolerant barley seed dissemination

Barley plays a critical role in the farming system in Salamieh district. The crop provides seed, an important ingredient in feed mixes, and straw that is an important source of revenue to land holders who rent out their lands for grazing to sheep herders. Given the vagaries of weather, providing farmers access to seeds of drought tolerant barley cultivars is an important measure in mitigating the risk of drought and low rainfall.

Adoption of new cultivars in the dry areas of Syria has been much slower than in the more favourable climates. Field experiments have indicated that new barley cultivars can provide up to 20% higher yields without the need for additional inputs, however, uptake has been slow (ICARDA 2005) and reasons could be many (see Mazid et al. 2007). In the past few years, a number of improved cultivars have been released by the Ministry of Agriculture of Syria because of their higher yield and superiority compared to the current

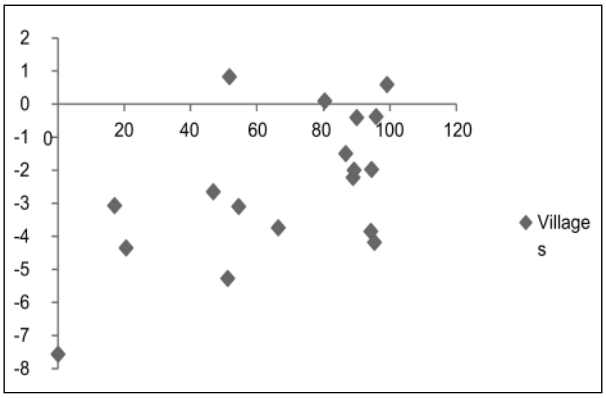

Figure 4. Scatter diagram of the difference in water table depth (in meters on the vertical axis) against percentage of land under modernized irrigation (shown by the horizontal axis) during the 2007/08 growing season in 19 villages.

prevailing cultivars. Formal seed sector has, however, not given much attention to producing seeds of these cultivars for various reasons (Mazid et al. 2007). Success of farmer to farmer exchange of seeds in aiding the diffusion of modern cultivars to small scale farmers in the absence of formal supply systems is being increasingly recognized (Almekinders et al 2007).

Accessibility to the new cultivars is often hindered because of the large gap between release of a new cultivar by the General Commission for Scientific Agricultural Research (GCSAR) of Syria, and the dissemination of its seeds to the farmers; this can be up to 10 years for strategic crops such as barley, wheat, potato and sugar beet. Thus by the time the seed is available to farmers much of the vigour of the original cultivar is often lost, as farmers tend to get seeds from other farmers rather than from the General Organization of Seed Multiplication (GOSM) of Syria.

As shown in Figure 5, the normal route of the improved seeds starts from the GCSAR which approves the release of a new cultivar after multi-year multi-location testing, the GOSM, which is responsible for producing the seeds, and then the farmers. The intervention of the alternative seed program lies in reducing the time lag between the release of the cultivar by GCSAR and its access to farmers.

With this aim, seeds of three new barley cultivars ('Furat 3', 'Improved Arabic Abiad' and 'Furat 7' have been distributed by AKF since the 2003/2004 growing season. There are approximately 13,000 barley farmers in Salamieh district in 172 villages. Over the period from 2003/2004 to 2008/2009, 960 farmers in 123 villages have been given 100kg of seed at cost price. A sample survey was recently conducted within the area where seed was distributed to determine the extent of adoption of new barley cultivars and the extent of farmer-to- farmer seed exchange and to evaluate factors affecting cultivar adoption or rejection. A multistage stratified cluster design was used. The sampling frame consisted of villages where seed had been distributed at least two years prior to the survey. Forty six villages were divided into three stratas relating to agricultural zone. Five clusters were chosen at random within each stratum and a random sample of 8 households per cluster was interviewed. The study by Mazid et al. (2007) was useful in undertaking this survey.

Results showed that the proportion of land under the new cultivar was higher for irrigated lands than for rainfed. In zones 2 and 3 it was especially high, however, in zone 4 the local cultivar still covered the majority of the irrigated land (61%). In contrast, for rainfed farming, the local cultivar was still widely in use (Table 6).

Table 7 shows the frequency of farmers growing new, local, or mixed cultivars in different agro-ecological zones for irrigated barley. Overall, 53% were using new and 32% local cultivars across all stability zones. In zones 2 (71%) and zone 3 (58%), the majority of farmers were using only the new cultivar. However, in zone 4 both new and the local cultivars were being used. The new cultivars used by majority of farmers were Forat 2 and Firat 3. In zone 2, Forat 2 was the most common cultivar. Others used included 'French' and 'Improved Arabic'.

Table 8 gives similar information for rainfed barley. Overall, 73% of rainfed barley farmers used the local cultivars. About 20% of farmers surveyed across all zones have replaced the local cultivar with the new one. Forat 3, followed by Forat 2, were the commonly used new cultivars.

Farmers were also asked to provide reasons for their adoption or non adoption of the new cultivar. The positive characteristics most frequently cited were the 'good height' and 'tall heads'. These were followed by 'high tolerance to lodging' and 'better yield'. Low yield and non palatability to

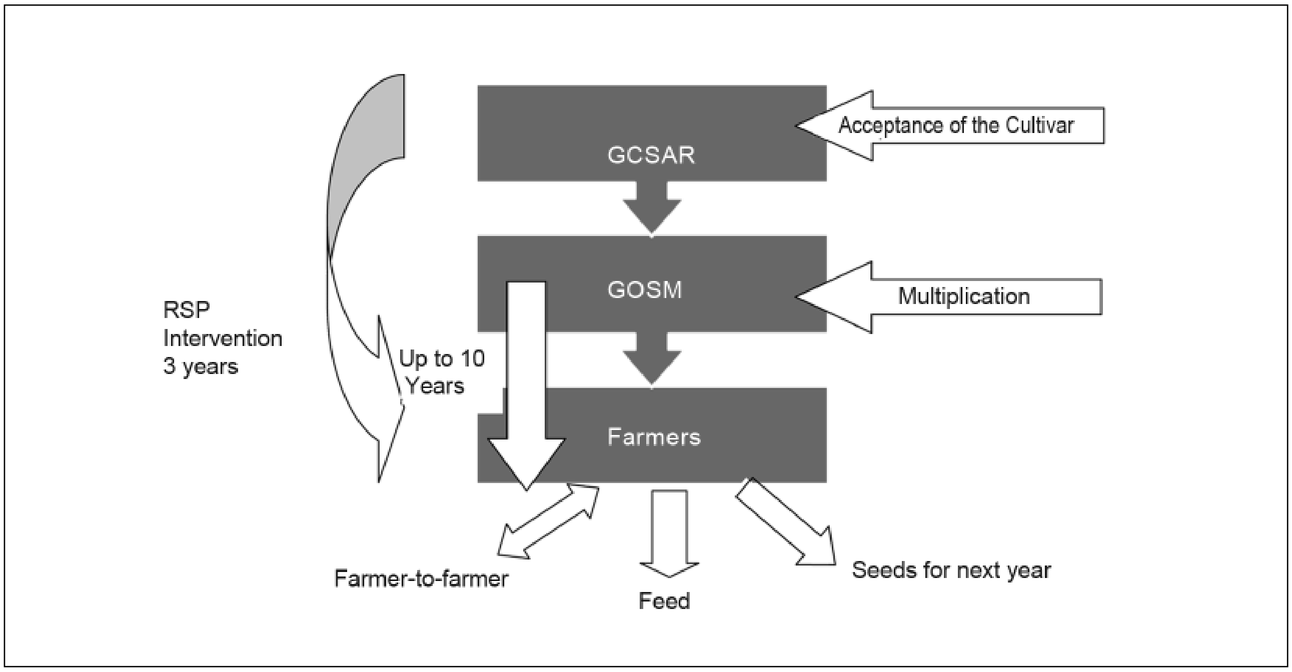

Figure 5. Flow diagram of seed distribution in Syria.

Table 6. Proportion (%) total barley area (*dunums*) planted with new and local cultivars in different eco-zones in Salamieh District in the 2008/2009 growing season.

	Zone 2		Zone 3		Zone 4		Total	
Type of area	**New**	**Local**	**New**	**Local**	**new**	**Local**	**New**	**Local**
Irrigated	74	26	67	33	39	61	53	47
Rainfed	19	81	32	68	12	88	22	78
Total area (dunums): Irrigated Rainfed	 327 2,123		 345 4,753		 763 3,988		 1,435 10,864	

Table 7. Number (No.) and percentage of irrigated farmers using new, local or both kinds of cultivars in different zones in 2008/2009.

Cultivar	**Zone 2**		**Zone 3**		**Zone 4**		**Total**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Only new	17	71	14	58	4	22	35	53
Only local	6	25	7	29	8	44	21	32
Both new & local	1	4	3	13	6	33	10	15

Table 8. Number (No.) and percentage of rainfed farmers using new, local or both kinds of cultivars in different zones in 2008/2009.

Cultivar	**Zone 2**		**Zone 3**		**Zone 4**		**Total**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Only new	10	29	9	19	3	9	22	19
Only local	24	71	33	72	26	76	83	73
Both new & local	-		4	9	5	15	9	8

sheep were some of the negative traits. In zone 4 where farmers were invariably growing local cultivars, 'less straw yield' and 'less palatability to sheep' than the local cultivar were reported as the cause of non adoption of new cultivars. Thus, for zone 4, where feed availability and livestock production is most severely constrained by drought, there is need for new cultivars with higher straw yield and with palatability equal to that of commonly grown local cultivars. AKF is now piloting the dissemination of 'Furat 7', a recently released cultivar for the region.

The differences in the adoption rate of new cultivars in different zones might be arising because of the difference in the motivation for producing barley there. Considering the apostrophe in government's guaranteed 'buy back' program, farmers in zone 3 may be more influenced by grain productivity of the cultivar rather than by its straw characteristics unlike the farmers in zone 4 who give more importance to livestock production.

Overall, the results (Table 9) showed that adoption rate of new barley cultivars (use of seeds for more than two years) was very high (on average 62%). In addition, farmer-to farmer seed exchange has played an important role in the diffusion as the transfer of seed to the neighbors at the village level is particularly high (one farmer giving seeds to three neighbours).

The distribution of new cultivars by AKF, over several years, has provided the main source of seed particularly in zone 3 where most of the seed was distributed. Overall 45% of farmers used AKF as their main source of seed (Table 10). This highlights that where both state and private seed companies are unable to distribute specific seeds, supply systems can be strengthened by using this model to help stimulate diffusion and uptake of new seed through farmer-to-farmer distribution.

It should be noted that adoption of new seed and technological advancements is not merely an issue of 'access'. There is also a need to address other issues, particularly the socioeconomic ones. These factors might assume more importance with recurrent episodes of drought as they would increase the cost of seeding and other agricultural inputs. The AKF is also assisting the farming community in this regard by facilitating the availability of group loans for seed purchase in areas most affected by drought.

4. New feed techniques, forage cultivars and livestock activities

The government estimates indicate that during the drought of 2008, some 800,000 heads of sheep (~ 40% of the sheep holdings at that time) were lost in Salamieh because of the decline in feed availability and significant price hikes of feed. AKF's flock management intervention is an important area of endeavor in this regard and aims at finding alternative ways to feed animals during periods of drought and to introduce best practices in weaning techniques. AKF also collaborates with a government initiative aimed at improving breeds and breed stock and facilitates the spread of better breeds of ewes and rams into the current stock of sheep in Salamieh district.

The second theme of importance for the livestock sector is the productivity enhancement through better forage use. This has the potential to both stimulate increase in overall feed availability and generate additional agricultural income for farmers. For example, the introduction of forage legumes into barley/barley or barley/fallow rotation improves soil fertility, which enhances yield and availability of fodder to feed livestock and thus improves milk and meat production (Al-Ashkar et al. 2005). A preliminary survey of 80 farmers in

Table 9. Total number (No.) and percentage of farmers adopting new cultivars (TA) as well as new adopters (NA) out of the total farmers (TF) growing barley in different zones, 2008/2009

	TA (No.)	TF (No.)	TA/TF (%)	NA (No.)	NA/TF (%)
Zone 2	21	28	75	7	25
Zone 3	15	30	50	15	50
Zone 4	11	18	61	7	39
Total	47	76	62	29	38

* Note Zone 4 includes one farmer that was supplied new barley to grow on a large scale by the government as an adopter

Table 10. Number (No.) and percentage of total farmers receiving seeds of new barley cultivars from different sources in different zones, 2008/2009.

Source of seeds of new cultivars	Zone 2		Zone 3		Zone 4		Total	
	No.	%	No.	%	No.	%	No.	%
Neighbors	9	32	7	26	3	21	19	28
Agricultural bank	4	14	0	0	0	0	4	6
Market	5	18	3	11	4	29	12	17
AKF	8	29	17	63	6	43	31	45
GOSM	2	7	0	0	1	7	3	4
Total	28	100	27	100	14	100	69	100

2009 indicated that farmers used a cultivar of forage legumes and some 81% of the sample would like to include a forage legume in their rotation. This aspect however needs more on farm study to quantify the magnitude of yield benefit on subsequent crop of barley by including legumes in the rotation.

5. Conclusion and discussion

The development projects being undertaken by the Aga Khan Foundation in Salamieh district have achieved much success in the field of drought mitigation namely:

i. A high degree of adoption of modern irrigation throughout the district with almost 95% the land under summer vegetables and fruit trees now covered with modernized irrigation equipment. Additionally, the practice is being increasingly adopted for growing winter crops.
ii. A high rate of adoption of new drought tolerant barley cultivars by farmers compared to local cultivars, albeit, still fairly low adoption on rainfed land particularly in zone 4.
iii. Provision of affordable credit through group loans for purchase of seeds of new cultivars, modern irrigation equipment and storage of fodder to promote diffusion of new technology and enhance resilience of the farmers most vulnerable to the impacts of drought.
iv. New feed techniques and forage legume dissemination which have received a positive response from more than 81% of farmers.

A number of challenges have also been presented that will undoubtedly shape future adaptation options for drought mitigation particularly in areas where water is becoming scarcer. These include the need for groundwater monitoring that may help to determine particular cropping mixes for certain interlinked areas within the basin based on their availability of water. This will be augmented by future advancements in agricultural research i.e. new drought tolerant cultivars and improved agricultural practices. However, a realistic government policy regarding water use in areas where water availability is likely to further decline will be a priority. Exploring options such as cropping restrictions, enforcement of legislation on new well drilling and/ or altering the price support systems are a few examples.

As the drought episodes become more frequent and the intensity of these "shocks" ever more severe – both from a hydrological and socio-economic perspectives – mitigation strategies will have to be accordingly formulated. Thus, although agricultural sustainability will be important, it should not be dealt in isolation. There will be a need for including a multitude of actors/program that will focus on 'human capital,' will enhance a community's ability to adapt to a rapidly changing climate, and will thereby seek opportunities for the future.

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New topics and high time pressure: Climate change challenges agricultural research in Central Asia and the Caucasus

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Abstract

The Intergovernmental Panel on Climate Change (IPCC) predicted in 2007 that average temperatures in the region of Central Asia could increase by 3.7°C by 2100. Such a change will have profound influence on the whole agro-ecosystem by affecting environment and various components of production pluralise system. It will also be severely reducing the population of pollinating insects on which the productivity and regeneration of economically important plants depend. Climate change is going to particularly affect the livelihoods of rural poor, who may entirely lose whatever few resources they might have, due to reduced yields and environmental disasters associated with the climate change. For sustainable livelihoods and production under changing climate it would be advantageous to go beyond the common focus on farmers that own land or livestock and target also the landless and the increasing number of female headed households. Interdisciplinary research in a number of key areas is suggested: (a) New methods to more precisely assess the adverse impact of climate change on various components and functioning of agro-ecosystems, including pollinating insects, so that appropriate interventions to cope with the impacts can be developed; (b) More intensified research on plant genetic resources, especially of aromatic herbs and medicinal plants, (c) Livestock research to enhance the small ruminants' endurance of long periods of water deprivation and exposure to high temperatures; (d) Integrated research on improving ecosystems resilience and the livelihoods of people dependent on such ecosystems; (e) Research to generate employment opportunities for the landless to prevent migration from rural to urban areas, and to empower women to become role models in livelihood diversifications through the use of high value crops and value chains. Such a refocused and reprioritized research agenda should be conducted in partnership with end-use stakeholders and linkages should be strengthened between the development agencies and civil society partners to ensure broad impact. Due to rapid climate change and highly sensitive nature of the mountainous ecosystems, the implementation of such a reprioritized and refocused research in the CAC region is becoming urgent.

Keywords: CAC region, climate change, pollinators, ecosystems resilience, high altitude region, livelihoods, small ruminants.

1. Climate change – a threat to food security in CAC

The Intergovernmental Panel on Climate Change (IPCC) has predicted an increase of regional temperatures in Central Asia (CA) by 3.7°C by 2100, which is much higher than the global average (2.8°C; IPCC 2007). On high altitudes the temperature rise will most probably be extreme. Climate change is forecasted to cause shrinkage of glacier volume in the CA region by around 32% by 2050 (WBGU 2007), a total loss of hundreds of small glaciers and a rise in evaporation, which will all lead to a significant loss of watering points on rangelands. CA as a whole will face a decline of precipitation by 3% and a shift towards more precipitation in winter but less in the growing seasons (IPCC 2007; SNC-UZB 2009). Crop yield decline is forecasted between 2.5-10% by 2020 and 5-30% by 2050 (IPCC 2007). Grasslands are expected to lose productivity by 30% (EDB 2009). Food production and to a very high extent also food security in CAC relies on local and regional agro-ecosystems, but some 40-60% of irrigated croplands in Central Asia are already salt-affected and/or water logged (Toderich et al. 2008).

The population in Central Asia is expected to grow from 60.6 million (2008) to 79.9 million by 2050, whereas in the three countries in the Caucasus it will slightly decrease (UNPP 2007). Stern Review (Stern 2006) and *Wissenschaftlicher Beirat für globale Umweltfragen* (WBGU 2007) regard Central Asia as one of the regions with the highest risk for conflicts due to climate change. Agriculture and agricultural research are already playing an important role in enhancing social stability and peace-keeping in the region. But as local problems are further accentuated by climate change, multilateral agencies might consider funding more agricultural research for adaptation to these changes.

There is also a need to widen the range of research topics and prioritize them afresh from the perspectives of 2030 or 2050. At present, agricultural research in CAC focuses mainly on conservation agriculture and efficient use of water in irrigated areas. Various technologies are available, but there is lack of impact. For example, the per capita annual consumption of water is quite high in the CA region (5324 cubic meters in Turkmenistan, 2351 cubic meters in Kazakhstan and 2292 cubic meters in Uzbekistan, in contrast to 485 cubic meters in China and 172 cubic meters in Morocco) with very low water productivity (UNDP 2009), perhaps because of lack of adequate dissemination of achieved results by development agencies. Current efforts on improving heat, drought and salinity tolerance of wheat, rice and other crops will require even more emphasis in the future because of the climate change. Plant Genetic Resources (PGR) research will require even more attention, specifically in mountainous areas where the risk of extinction of some species is high due to climate change. Wild species and medicinal plants in the mountainous areas might become important cash crops for 'green' pharmacies in the future, as the 'Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization' would enhance the economic return from them. They would therefore need special attention. Research on growing nutritious crops (fruits, vegetables, potato) would be important as they, like sorghum or amaranth, require less water than wheat, rice and cotton and are therefore promising options in the face of climate change. As the livestock production is highly threatened by climate change because of its adverse effect on pastures, research on crop-pasture-livestock integration would become increasingly important.

The climate change is also going to disrupt the interaction of interrelated species and thus cause significant system-wide changes within the agro-ecosystems in the CAC region. It is already endangering pollination services in various ways, increasing agro-ecosystem risks and food insecurity specifically in mountainous regions; causing shrinkage in arable land; and reducing productivity of cropped areas and rangelands. Therefore, a broader research portfolio, enhanced interdisciplinary research and linkages with other disciplines (including extension services) are needed to safeguard the livelihoods of rural poor rather than the traditional research focus on improving single crops or technology in irrigated areas.

2. Climate change will affect the functioning of ecosystems

The climate change related systemic changes within the agro-ecosystems are among the least developed fields of environmental and agricultural research, although their importance for agriculture is going to increase in the future.

2.1. Systemic changes within agro-ecosystems

IPCC Report (IPCC 2007) states that "Climate change is likely to lead to some irreversible impacts. There is medium confidence that approximately 20 to 30% of species assessed so far are *likely* to be at increased risk of extinction if increases in global average warming exceed 1.5 to 2.5°C (relative to 1980-1999). As global average temperature increase exceeds about 3.5°C, model projections suggest significant extinctions (40 to 70% of species assessed) around the globe." As the temperature in CA is projected to increase by 3.7°C by 2100, high rates of extinction of species would disrupt the interaction of interrelated species. The temperature rise will also change seasonal development patterns of individual species and affect the 'clockwork' (natural synchronization) of the (agro-) ecosystems (Christmann et al. 2009; Ssymank et al. 2009). These agro-eco-system changes have to be monitored by environmental research, but appropriate research approaches are yet to be developed (MA 2005). Worldwide research on the impacts of climate change on biodiversity and (agro-) ecosystems and on the economics of ecosystems and biodiversity (TEEB 2008, 2010) has only just started and it will have to be intensified to keep up with the ongoing changes.

"Preserving interactions among species is critical for maintaining long term production of food" (MA 2005). Even in the regions that are less affected by the climate change, like Europe, the change has already started disrupting the matching of inter-dependent species. For example, there is evidence for behavioral changes in various insects and migrating birds (NABU 2008) that would influence agricultural productivity. Climate change will also encourage the spread of invasive species, enhancing the vulnerability of ecosystems (IPCC 2002). Agro-ecosystems greatly depend on the activities of pollinators, beetles, and worms for their sustainability. If for instance the local dung beetle species goes extinct due to climate change, this will quickly change the composition of meadows and rangelands and significantly reduce biodiversity.

There is a need to identify early indicators for systemic changes within agro-ecosystems and their synchrony. Without such indicators agricultural research cannot develop measures for quick action in case of urgency. The more climate change progresses, the more agricultural research will depend on research cooperation for biological and ecosystem monitoring and on modeling of climate change related impacts on agro-ecosystems. To identify indicators and probable timelines for systemic changes, researchers specializing in agro-ecosystems, agriculture, and taxonomy will have to work together with a special branch of mathematics, chaos theory, which analyses the behavior of dynamic complex nonlinear systems that are very sensitive to initial conditions. But, studying the changes induced by climate change in systems such as pastures is a highly challenging task.

Pastures are being influenced by higher temperatures through the changes in seasonal growth patterns, increased evaporation, extinction of species, appearance of invasive species and changes in migration pattern of birds and beneficial insects. All these changes have significant impact on the interactions of the local plant and animal species, because of they may cause a break down of synchronized processes. For example the time when host plants would become ready to provide feed for the pollinating insects may not match with the period when the pollinators are most abundant. Chaos theory cannot predict future behavior of complex systems, but can give insight on dependencies and typical behavior (Peitgen 2005). The questions that need to be answered include: How do ecosystems react, if 20 or 40% of species go extinct? Which species are most valuable to maintain or to regain some balance or a certain agricultural productivity? Pollinators might be among these most valuable species, also insect predators such as the ladybird beetle, but there might be more. The use of present predator-prey-models like those of Lotka-Volterra, Kermack-McKendrick, Ricker (Gleick 1987; Kot 2001) would give much more insight on the dynamics caused by accelerated disruptions within the clockwork of ecosystems in the course of climate change.

Taking up such examples from agro-ecosystem research to the agricultural research in CAC might diversify its research approach. The present predominantly 'linear' or 'isolated component' approach might not be sufficient to address the changes occurring in the complex and highly sensitive agro-ecosystems facing drastic climate change. Adoption of systems approach might be better. Integrated pest management (IPM) is already a step in this direction. The research, with systems approach, that supports more the beneficial components of agro-ecosystems would also lead to sustained crops and livestock production even under the conditions of progressing climate change.

2.2. Increasing importance of wild insect-pollinators

CAC is one of the regions with the most precious agro-biodiversity. It can therefore develop into a center of research for developing knowledge on climate change adaptation and conservation of agro-biodiversity, which might later be useful also for other areas. Most important to avoid the loss of biodiversity and a collapse of agro-ecosystems due to climate change is the research on insect-pollinators. Biodiversity and food security depend on the ecosystem services of pollinators (at present, to a high degree, the honey bees, *Apis mellifera*). But in the high altitude areas of CAC the wild pollinators are the main service providers. Unfortunately, little is known about their habitat requirements and the way their role could be optimized by the local communities under changing climate. Worldwide there is a decline of pollinators due to various stress-factors and climate change might become one of the most severe threats to pollinator biodiversity (FAO 2008b).

Long term (three decades) research in the Rocky Mountains showed that the activity of migratory pollinators is already getting out of the traditional synchrony with flowering (Science Daily 2006).

Research on honey bees is necessary, as during pupal development they are highly sensitive to changes of temperature. (Tautz et al. 2003). Bees regulate the temperature in the hives themselves, but abrupt extreme changes in ambient temperatures because of climate change might exceed their capacity to regulate. Experiments in Brazil showed that adult honey bees abandon the nest when the temperature in the hive exceeds 41°C (Imperatriz Fonesca et al. 2009). The tolerance of local honey bees to climate change has to be studied in CAC, and adaptation measures developed.

The worldwide economic value of the pollination by bees and other insects was estimated to be €153 billion in 2005 for the main food crops (about 9.5% of the total value of the world agricultural food production) and the disappearance of pollinators would cause crop losses worth €190 to €310 billion (Gallai et al. 2008). Central Asia is the second most vulnerable region of the world in terms of the loss in crop yield because of potential loss of pollinators (Gallai et al. 2008).

The economic loss vulnerability is high for fruits (41%), nuts (35%), edible oil crops (25%) and vegetables (14%). Whereas fruit production at present exceeds fruit consumption in Central Asia by 31%, pollinator loss would lead to a deficit of 22% (Gallai et al. 2008). Gallai et al. (2008) based their vulnerability (exposure, sensitivity and adaptive capacity) research on the main internationally traded food crops for direct human consumption, but there are many other plant species dependent on pollination services that are only regionally traded and hence of great regional importance. Also, pollination services for plants used for feeding livestock (e.g. alfalfa and clovers) are not included. Therefore, the vulnerability of people living in the Central Asian mountain villages, who either depend on orchards, gardening, nuts, herbs and livestock, or are employed as labor in agricultural operations, might even be much higher than that suggested by these figures.

"The loss of particular pollinator species … reduces the resilience of the ecosystem to change" (FAO 2008b). Cross pollination promotes biodiversity and is therefore of extremely high value for adaptation of agro-ecosystems to climate change. The extinction of a pollinator species brings the risk of "community-level cascades of decline and extinction … whereby decline of some elements of the biota leads to the subsequent loss of other species that directly or indirectly rely upon them" (Biesmeijer et al. 2006).

Due to climate change the patterns of seasons will become more and more unreliable, reducing the activity of honey bees, which are sensitive to cold and wet weather and darkness. Wild pollinators are better in this regard, but their range of flight is rather limited. Wild pollinators might develop to become a safety net for farmers for wet and cold days in case early action is taken to protect them from extinction. Methods to increase yields in quality and quantity by improving wild pollinator services (e.g. www.xerces.org) are underdeveloped in CAC and need attention as they do not require high financial input and are thus affordable for the poor. Research in CAC should develop information on how the improvement of habitats for wild insect-pollinators close to the fields and orchards can increase quality and quantity of produce of different crops (e.g. watermelon, fruits, vegetables, oil seeds, herbs, canola, alfalfa etc.). The development of best-practice guidelines and protection legislation might be promising options. Agricultural research organizations might also change their own fields where bare sites without shrubs and trees prevail, and diversity is low, which does not auger well for sustainable integrated farming (EISA 2001). Guidelines for habitat improvement for wild pollinators on all research sites would be a win-win situation in various ways (local biodiversity, data base, demonstration effect).

3. Need for more focus on mountainous regions

Extremely rapid climate change and high exposure to related disasters, high poverty and food insecurity, drastic social changes by out migration (mainly of men), and greater risk to biodiversity are the reasons that necessitate enhanced agricultural research efforts in relation to climate change in mountainous areas. Globally, about 50% of total crop production originates from forest and mountain ecosystems (FAO 2008a), and in mountainous CAC products like nuts, fruits and meat are quite important. Climate change will increase the ongoing decline of mountain agriculture in CAC. Increasing poverty in this region will trigger labor migration, putting pressure on the lowlands and neighboring countries and thus increasing the risk of social and political tension. To prevent this, accelerated re-orientation of agriculture research would be needed.

At higher altitudes an increase of temperature might prolong the potential growing season (Robinson and Engel 2009), but due to water scarcity, increasing seasonal abnormalities and probable disruption of the 'clockwork' of ecosystems, the benefit of a prolonged growing season might be unrealizable. The future agricultural research in mountainous regions should therefore reorient itself to harness full potential of the region under changing climate.

In addition to the single commodity linear research, which is essential for the production of sufficient nutritious food, at least three more target areas would need attention. Firstly, efforts will have to be made to develop strategies to protect rural poor from losing their small land holdings (or the few animals they might have) and becoming deprived of their productive assets. The increased frequency of climate extremes and disasters reduces the time for poor households to recover from one climatic shock to another (von Braun 2008; von Braun et al. 2008), whereas diversified sources of income can safeguard a household. Secondly, strategies will have to be developed to re-integrate the poorest strata of the society into agriculture on a higher level of economic activity than merely as cheap daily labor. At present the target groups of agricultural research are those, who have at least some small assets, but not the rural poor completely deprived of their productive assets. Thirdly, strategies would be needed to reduce the vulnerability of livelihoods of mountain people to climate change related disasters such as soil erosion, avalanches, mudslides and floods.

Research projects that contribute to all the three Rio-conventions (UNFCCC, UNCCD and CBD) foster new balances in agro-ecosystems (based on systems research), protect wild pollinators, promote building of catchments, terracing etc., and have a strong focus on value chains (e.g. green pharmacies), can reduce the vulnerability of livelihoods in times of rapid climate change. The research should be anticipatory keeping in view the changes expected by 2030 or 2050 and use a livelihood and agro-ecosystem design.

3.1. Water scarcity

As mentioned before, water scarcity, mainly caused by glacier melt and higher evaporation losses, will affect mountain agriculture and livelihoods significantly. A lot of smaller glaciers (less than 1 km^2) in Central Asia will most likely disappear by 2050 (WBGU 2007; Tajik Meteor Service 2003). Areas still having strong water streams and local hydropower will develop into areas of severe water scarcity within a few decades. Farmers accustomed to irrigated agriculture would need time to adapt to rainfed farming. At present, research is focused mainly on developing GIS-maps for the area. To get data on the conditions to which agriculture will have to adapt, additional research on local ecosystems would be necessary to answer such questions as whether all small glaciers will melt off, and whether it would be possible to build water catchments, where and how? Glaciers not only add water to the yearly precipitation received in the lower areas but also regulate the timing and flow of this water down-stream. With the disappearance of glaciers, the down flow of melted snow will be earlier (in March and April, rather than in May and June) making agriculture entirely dependent on the seasonal precipitation. Also, socioeconomic research will be needed regarding (a) the availability and use of water resources from different sources (rain or glacier melt) by villagers to meet their specific demands, and (b) on the capacity of villagers to adapt to water scarcity by using mountain wild or cultivated rainfed crops that are tolerant to rapid climate change and amicable for inclusion in value chains, conservation agriculture, harnessing landscape ecology, reforestation, and building of water catchments, terraces etc.

Evaporation will increase with the increasing temperatures and even the high altitude large lakes would be at risk. For Issyk–Kul Lake in Kyrgyzstan, the world's second biggest mountain lake (6,232 km^2), the water surface is expected to be reduced significantly, in the range from 232 to 1,049 km^2, by the end of the century (SNC-KYR 2009. The preliminary assessments for lake Chatyr-Kul, under most climatic scenarios, indicate that it can exist merely as a small reservoir, drying up completely every year (SNC-KYR 2009). Increased evaporation would lead to a significant decrease in soil moisture, reduced vegetation and thus increased soil erosion. Major efforts to adapt crop production and rangeland vegetation to reduced moisture supply will therefore be needed.

Pastoralists are likely to be specifically disadvantaged by a decrease in the water resources. Mountain pastoralists depend more on natural water points like small rivers or lakes close to the rangelands for watering their animals than the pastoralists in the lowlands, because it is not economical or feasible to bring water to remote summer rangelands on high altitudes or to dig wells there. While there will be rainfed grasses available on the large mountainous rangelands in spring, but, with no watering points anymore, they may become useless for the herds. In the Khatlon-area in Tajikistan and in southern Kazakhstan for instance, it is already common to have grazing on one day and let herd walk next day to a watering point, whereas the Ethiopian and Somali pastoralists bring their goats and sheep to water points only once every 5 to 8 days (Mengistu et al. 2007). It would therefore be necessary to integrate and focus on water-related aspects also in the livestock-research.

To ensure future livestock production more efforts would be needed on three important aspects: (1) identification of suitable sites for developing small water catchments in the rangelands where seepage and evaporative losses are minimum; (2) breeding efforts on small ruminants not only for improved meat and wool production but also for enhancing their ability to continue grazing for a long time even when deprived of water during the periods of drought, and (3) developing sustainable options for intensified production of high income goat and sheep breeds that need frequent watering and controlled feeding, based on raising them in fenced areas linked with assured forage production, to avoid present overgrazing of rangelands close to the settlements. If this is not done, the entire livestock production in the future will be possible only by growing fodder as the use of the rangelands would not be possible due to lack of natural watering points. This is already happening around Tso Kar Lake in Ladakh, northern India where pastoralists cannot use rangelands anymore because the water in this high altitude lake has become too salty due to evaporation (Christmann 2006; Demske et al. 2009). Kyrgyzstan and Tajikistan do not have an abundance of rangelands, so this would significantly affect livestock production. Abandoning the grasslands might also adversely impact the biodiversity (Körner 2003).

3.2. Labor migration

More focus on climate change related water scarcity is also desirable to reverse the current trend of migration of labor force from mountains to lowlands, particularly in Tajikistan and Kyrgyzstan. In Tajik mountain villages, families do not invest in crop production anymore, and there is large migration of the work force (about 90% male), from there to lowlands and neighboring countries to earn and remit back. Nearly one million Tajik migrants are reported to be working in Russia, remitting back money that may amount to nearly 30 to 46% of Tajikistan's GDP (Marat 2009). The families invest this money in goats, whose number has swelled from 870,800 in 1992 to 1,202,300 in 2007 (FAOSTAT 2009). This increases overgrazing and soil erosion around the settlements due to lack of manpower to take the animals to higher elevation summer pastures. Goats also harm pastures in dry areas much more than sheep, enhancing land degradation and instability of alpine soils. Therefore, high income goats should be raised on forage-based feeding and water supply in small fenced yards, rather than on rangelands.

Migration is leading to an increase in the female-headed households and thus changes the target group for agricultural research. These women mostly work as low-paid daily-wages workers in the agricultural sector. The number of female farmers heading the enterprise is increasing (Christmann et al. 2009), although their financial resources are limited because the remittances from their migrated family members is relatively small, and some do not even care to send any money (Glenn 2009). The social status of women and children of families whose men folks have migrated out is very low and they are often exposed to exploitation. Agricultural research for CAC mountain villages will have to address this issue by making agriculture more profitable even on marginal land and by developing job-creating value chains in order to prevent migration of men. Agricultural research might also generate sustainable investment alternatives for remittances (e.g. protected agriculture, post-harvest processing facilities). Research should also address the needs of female farmers and pastoralists, particularly of those that get abandoned by the migrants with no rights to any assets. The increasing number of decision making female farmers provides an opportunity for accelerated vocational change towards growing fruits, vegetables, herbs and medicinal plants, producing honey and undertaking value addition through post-harvest processing. The women farmers would however need appropriate tools and equipment and training. Research on value-addition and market chains is therefore desirable.

Mountain terraces and other resource conserving structures in CAC were traditionally maintained by men folks. Because of their migration these structures are at risk of degradation. But, with increasing water scarcity the importance of these structures will rise in the future. Therefore, agricultural research for development will have to take an integrated approach to break the vicious cycle: deterioration of mountain agriculture causing out-migration of male workforce from villages leading to enhanced vulnerability of the remaining inhabitants to climate change; this in turn reducing the chances for the younger generation to develop capacity to cope with future challenges, because poverty and reduced respect for their abandoned mothers is already depriving them from education and healthy development (Glenn 2009); increased poverty leading to further degradation of land, loss of biodiversity and deterioration of agriculture.

4. Crop diversification and value chains

Agriculture will continue to be important for social stability in the CAC region. However, the arable land per capita is already very low (except in Kazakhstan and Turkmenistan), and water scarcity will increase with ongoing climate change. Research on crop diversification (based particularly on water and other ecological footprints of the products), value chains and marketing options are necessary to enable mountain farmers get higher income on the same plot of land with less water and no negative effects on the ecosystem. This requires more interdisciplinary research (socioeconomic, environmental, and agricultural aspects); including the study on the merit of creating a common economic market for CAC. Its proximity to Russia, Ukraine, China and India can offer enormous opportunity of value added goods based on fruits, vegetable, and herbal and medicinal plants. The south-eastern neighbors, with more than 40% of the world population, are already net importers of food.

Thirty seven crops have been identified as promising alternatives in subtropical West-Georgia for targeting the European markets, with berries, subtropical fruits (kiwifruit, feijoa, persimmon etc.), cabbage and topinambur (Jeruselum artichoke) described as best options (Bedoshvili et al. 2009). Most of them, except the berries, might be suitable also in South East Azerbaijan (Lenkorian). For Khorezm, Uzbekistan, gooseberry, sour cherry, pistachio, jujube, date, fig, almond, barley, topinambur, safflower and tobacco also have good future prospects for export to Europe (Kohlschmitt et al. 2007). Due to similar agro-climatic conditions these plants might be suitable for Karakalpakstan, northern Turkmenistan and southern Kazakhstan. Success with all these crops will depend on good protection of pollinators.

Specifically for the poorest having limited or no land, it is necessary to focus more on labor-intensive crops such as fruits and vegetables that can be raised around their dwellings, and on sustainable use of wild plants like nuts, sea buckthorn (*Hippophae ramnoides* L.), rose hip, black elder, blackberry, fig, mulberry, mustard, herbs and medicinal plants. Some wild plants have potential for value chains, like sea buckthorn, a fast growing fruit tree along the river beds, which simultaneously decreases the risk of erosion by deep roots, provides vitamin-rich fruits and firewood. If the forests are sustainably managed, the expansion and commercialization of non-timber forest products might increase the cash income of rural households. The large walnut (*Juglans regia*) forests in Kyrgyzstan have a high potential and require urgent protection for sustainable use – for instance by the Forest Stewardship Council (FSC; www.fsc.org).

There is also a need to increase research on forage production on marginal and saline lands and to develop integrated agro-pastoral-systems. Sorghum, for instance, is tolerant of salt and drought (Rehm and Espig 1991). Results from a study done by International Center for Biosaline Agriculture (ICBA) showed that sorghum could produce 97.9 t/ha green biomass within 3-4 months on saline lands in Uzbekistan. Sorghum, pearl millet,

Box 1. Overview of the new directions in which research needs to be directed for enabling vulnerable communities in CAC to cope with the impacts of climate change.

Current research thrust	New directions needed
Heat, drought, salinity tolerance in wheat, rice and maize	Continue, but also increase focus on other crops which are more adapted to heat, drought and salinity such as sorghum, pearl millet, topinambur, etc.
Improvement of nutrient rich crops (potato, vegetable, fruits, melon)	Continue, but also increase focus on nuts, oilseeds and cereals for health foods
Plant genetic resources management (*in-situ* and *ex-situ*)	Increase focus on high altitude plants (herbs, medicinal plants), halophytes and plants adapted to extreme habitats to enable farmers to benefit from Nagoya Protocol and 'green' pharmacies.
Single crop and location specific research	Emphasize multidisciplinary research in projects designed for agro-ecosystems, livelihoods and value chains; include research on ecosystems, chaos theory, and socio-economic and political science. Start research on pollinating insects on priority basis.
Linear research approach	Additionally adopt systems approach.
Livestock research focused mainly on meat and wool production; forage production	Change priorities - ability of sheep to endure short duration water deprivation; high income goats in fenced areas; expand research on forage production and dual purpose crops, grazing management and value chains.
Irrigated and rainfed areas	Mountainous regions; marginal and saline lands.
Sustainable land management	Primarily emphasize the extension of the results already achieved in this field of research.
GIS mapping	Continue, but add research on identifying areas for water catchments on high altitudes and increase interaction with socio-economic research to assess economic impacts on rural livelihoods and local adaptation capacity.
Modeling impact of climate change	Expand the work on integrated (biophysical and economic) modeling of climate change impacts that has been just started under the ICARDA-IFPRI-NARS joint project.
Male farmers and herders	Continue, but add rural poor deprived of capital assets.
Households headed by men	Households headed by female farmers and women working on daily wages.
Extension by Farmers' Days, etc.	Establish links between research and extension organizations (development sector, NGO, private companies); focus on research but ensure wide dissemination of results through the extension services.

barley, safflower, amaranth, triticale and licorice have potential as fodder-crops on sandy desert and longtime irrigated saline areas, providing good income and simultaneously improving the soil quality. Shrub/tree-avenues to safeguard forage/grain crop strips would act not only as wind breaks but will also prevent wind erosion and provide shelter for birds, pollinators and other ecologically important species. As the demand for healthy cereals increases in Europe and the US, more focus on the nutritional quality might contribute to better income opportunities from cereal crops (Sands et al. 2009; Morris and Sands 2006). It a challenge for breeders to develop gluten free cereals, but introducing new crops from old world like Teff (*Eragrostis tef*), common in Ethiopia and Eritrea, is possible as it does not contain gluten and is rich in iron. It is already becoming popular in Germany and the Netherlands.

Various halophytes can be grown for forage, food, energy, edible oil, fibers, and traditional medicines. Interest in biosaline agriculture is increasing amongst the farmers as a feasible option for their marginalized farms. Thus, the demand for seeds of salt-tolerant species is increasing. Innovative programs are needed to develop and multiply seeds of salt tolerant plants and device modern crop management techniques to establish them within natural plant communities and in different suitable ecosystems. These activities would improve the livelihoods of the poor in the semi-deserts and make them more resilient against climate change (Toderich et al. 2009). Developing options to combine such research with quantified CO_2 storage on grasslands within the flexible instruments of the Kyoto-Protocol will be of value because these would contribute not only to increased forage production, but also to climate change mitigation, desertification control and poverty reduction.

Countless pharmaceutical plants (e.g., *Mandragora officinarum*, *Achillea millefolium* and *Valeriana officinalis*) grow in CAC mountain areas (Christmann et al. 2009) which could be of use in harnessing benefits from the Nagoya Protocol. But without agronomic, biochemical and economic research it may not be possible to sustainably grow them, fully exploit their potential and protect their habitat for *in situ* adaptation to climate change. Valuable medicinal species grow also in the sandy desert areas, for instance species of genera *Ferula* and *Berberis* (Gintzburger et al. 2003). *Ferula assafoetia* provides fodder, spice for culinary use, and flavor for perfumery besides being of medicinal value (Brown 1995). The plant has a very wide environmental adaptation as it can tolerate a temperature range from below 0 to 50°C as well as high levels of salinity (Huxley 1992). Wild forms are common in large abandoned lands affected by salinity and in semi-desert areas in Central Asia. Commercial cultivation of this plant can contribute significantly to safeguarding livelihoods of the people, but only after adequate research on production agronomy and technological aspects of the crop.

OECD estimates the pharmaceutical value of biodiversity “in the multi-billion dollar range” (OECD 2008). Various regions characterized by subsistence and smallholder agriculture are “storehouses of unexplored biodiversity” (Easterling et. al. 2007), but “species with limited climatic ranges, and/or restricted habitat requirements and/or small populations are typically the most vulnerable to extinction, such as endemic mountain species” (IPCC 2002). Research focused on protection of the genetic resources of herbs and medicinal plants and their cultivation for ‘green’ pharmaceutical products can become strategically important to revitalize mountain and desert agriculture in the CAC region.

5. Cooperation as a means to increase research impact

There is urgency for implementing the adaptation measures in CAC because of the high vulnerability of the region to the impact of climate change. There is a need for very close cooperation between the researchers, extension workers and the farming communities to start using the results already available and to undertake anticipatory research and research with new direction (Box 1) in a participatory mode to achieve outputs that would be quick to adopt. Climate change forces mankind to rethink the way research and development programs are conducted so that the most vulnerable economies could be restructured ‘at wartime speed’ (Brown 2006). Agricultural research for development would serve as a major ‘peace-keeping force’ in the areas most challenged by rapid climate change, as is the region of Central Asia and the Caucasus.

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AMMAN DECLARATION ON FOOD SECURITY AND CLIMATE CHANGE IN DRY AREAS

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The Intergovernmental Panel for Climate Change and agricultural development experts have highlighted that the world's dry areas will be severely affected by climate change, putting at high risk agricultural production, food security and human livelihoods in these already vulnerable areas, and urgent coordinated efforts are essential to develop both effective climate change adaptation strategies and mitigation measures. More than 200 policy decision-makers and scientists from 29 countries met in Amman, Jordan, on 1-4 February 2010 at the International Conference on Food Security and Climate Change in Dry Areas.

Recognizing that:

- The temperate and semi-tropical dry areas occupy about 40 percent of the earth's total land area and are home to 30 percent of its people, the majority located in the developing world. Of these, a large proportion, especially the poorest and most marginalized, live in rural areas practicing mixed crop/livestock/rangeland production systems.
- Characterized by water scarcity, the dry areas have less than eight percent of the world's renewable water resources and are challenged by frequent droughts, extremes of temperature, land degradation and desertification. Poverty is disproportionally concentrated in dry areas; population growth rates are high; women and children are highly vulnerable and 16 percent of children are malnourished. Out-migration is common.
- Climate change will have serious implications for further degradation of natural resources, including the unique biodiversity, and increase already existing food insecurity and poverty.

We, the participants of the Conference, pledge to:

- Establish and participate in an international food security and climate change network that will identify and share adaptation, mitigation and ecosystem resilience solutions to enhance food security to counter the effects of climate change in dry areas.
- Mobilize science, technology, and human, physical and financial resources to support research and integrated development activities, and enhance regional and international cooperation.
- Promote the following specific actions within national, regional and international organizations, with private sector partners, and in particularly farming communities.

Actions

To enhance food security and reduce vulnerability to climate change, the following activities are prioritized for emphasis and action.

1. Natural Resources (Land, Water and Biodiversity)

- Collect and ensure the long term conservation and utilization of biodiversity, including crop wild relatives and landraces, before it is lost.
- Focus explicitly on water conservation, productivity and sustainable management of increasingly scarce water resources in rainfed and irrigated production systems with the participation of land- and water-users.
- Address land degradation through integrated agro-ecosystem-based approaches, including crops, livestock and rangelands, aiming for overall food production system resilience and sustainability.
- Promote the net, long-term sequestration of carbon in soils and above ground biomass within dryland land use systems.

2. Food Production Systems

- Develop crop varieties and animal breeds resistant to drought, extreme temperatures, salinity and other stresses, and integrated soil, crop, pest and disease management practices.
- Diversify and improve the management of farming systems, including the use of crop rotations, conservation agriculture, effective and efficient use of water and other agricultural inputs.

- Identify and implement strategies to enhance adaptation which will further mitigate greenhouse gas emissions (CO_2, CH_4 and N_2O) within mixed crop/livestock/rangeland systems.

3. Policies and Institutions

- Strengthen policies and institutional structures that enhance the adoption of improved technologies and promote the sustainable and equitable use of common biological, water, and land resources, particularly rangelands.
- Reinforce and increase investments in national, regional and international agricultural research systems to enhance their agricultural research and development programs to improve food security and cope with climate change.
- Ensure that 'climate change-proofing' is comprehensively considered in all governmental and private sector initiatives, policies and development strategies.
- Strengthen capacity development in research and technology transfer.

4. Energy

- Develop sources of renewable energy (solar, wind, etc.) for sustainable food security and mitigating the effects of changing climates.

5. Regional Initiatives

- Establish a Regional Commission for Food Security and Climate Change in dry areas involving all stakeholders to enhance regional cooperation in matters related to food security and climate change, with ICARDA taking the coordinating role.
- Establish a regional network for weather monitoring, and market information, and a dissemination system for farmers towards adapting their planting, efficient watering and harvesting decisions.
- Establish knowledge system on the adaptation and resilience practices in response to climate change, particularly drought and extremes of temperatures.

The fragile dry areas of the world are at the forefront of the international battle to confront the effects of the climate change, and we the participants of the Amman Conference on Food Security and Climate Change, pledge to work together with farming and livestock communities to adapt and cope with the effects of climate change towards enhancing food security.

We appeal to the scientific community, policy makers and the donor community, as well as national, regional and international organizations, to give priority in their research, investments and activities, towards enhancing food security and coping with climate change implications in dry areas.

We request ICARDA to coordinate implementation of this declaration by all partners and to keep all stakeholders informed on developments in this regard.

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Appendix 2: Conference Program

Monday, 1 February

09.00-10.15 **Opening session**
Guest of Honor: H.R.H. Prince El Hassan Bin Talal

Welcome by Director General ICARDA, Dr Mahmoud Solh, on behalf of ICARDA and partners
Welcome by Director General NCARE, Jordan, Dr Faisel Awawdeh
Statement by Chair of GFAR, Dr Adel El-Beltagy
Statement by H.E. Minister of Agriculture of Jordan, Eng Saeed Masri
Inaugural Address by H.E. Prime Minister of Jordan, Mr Samir Rifai
Guest of Honor Address: H.R.H. Prince El Hassan Bin Talal

11.00-12.30 **Plenary session 1**
Co-chairs: Adel El-Beltagy, Gareth Wyn Jones
Impact of climate change on agriculture in the dry areas
Mahendra Shah
Ensuring food security in a changing climate: how can science and technology help?
Mahmoud Solh

13.30-15.00 **Plenary session 2**
Co-chairs: Mahmoud Solh, Faisel Awawdeh
Role of GFAR in reducing climate change impact on food security
Adel El-Beltagy
Impact of climate change on food security and livelihoods
Mark W. Rosegrant

15.30-17.30 **Concurrent sessions - A**

Theme 1-A: Current status of climate change in the dry areas: simulations and scenarios available
Co-chairs: Mahendra Shah, Abdolali Mohamad Ghaffari

Mapping drought extent, severity and trends using the Standardized Precipitation Index
Eddy De Pauw
Generating a high-resolution climate raster dataset for climate change impact assessment in Central Asia and northwest China
François Delobel, Eddy De Pauw & Wolfgang Goebel
Analysis of Jordan's vegetation cover dynamics using MODIS/NDVI from 2000-2009
Muna Saba, Ghada Al-Naber & Yasser Mohawesh
Application of the IHACRES rainfall-runoff model in semi-arid areas of Jordan
Eyad Abushandi & Broder Merkel

Theme 2-A: Impacts of climate change on natural resource availability (especially water), agricultural production systems and environmental degradation in dry areas
Co-chairs: J.S. Samra, Abd Shukar Abd Rahman

Climate change and water: challenges and technological solutions in dry areas
M. Karrou & T. Oweis
A land suitability study under current and climate change scenarios in KRB, Iran
A. Gaffari, E. De Pauw & S.A. Mirghasemi

Theme 3-A: Impacts of climate change on food security, livelihoods and poverty
Co-chairs: Azzam Tbeileh, Hammou Laamrani

Adaptation to climate change in dryland agriculture: issues and implications
Mohamed A.M. Ahmed
Food security in the occupied Palestinian territory
Jad Isaac & Nader Hrimat

Tuesday, 2 February

09.00-10.30 **Plenary session 3**
Co-chairs: Mahmoud Duwayri, Raj Paroda
Applying a broadened genetic base in crop breeding
Calvin O. Qualset
Genetic resources, climate change and the future of food production
Luigi Guarino
Faba bean and its importance in food security in the developing countries
José Ignacio Cubero Salmerón, Carmen Avila & Ana Ma Torres

11.00-12.30 **Plenary session 4**
Co-chairs: Khalfan Al-Naabi, Awni Taimeh
Changes in extreme climatic events and their management in India
J.S. Samra
The Green Morocco Plan in relation to food security and climate change
Rachid Dahan for Mohamed Badraoui

13.30-15.00 **Plenary session 5**
Co-chairs: Mohamed Shatnawi, Ayman Abu-Hadid
Addressing concerns of climate change and food security in the Asia-Pacific region
Raj Paroda
Achieving 'more crop per drop' in a changing environment
Theib Oweis

15.30-17.30 **Concurrent sessions – B**

Theme 1-B: Current status of climate change in the dry areas: simulations and scenarios available
Chair: Rana Kawar
Trend analysis for rainfall and temperatures in three locations in Jordan
Yahya Shakhatreh
Monitoring the vegetation dynamics as a response to climatic changes in the eastern Mediterranean region using long-term AVHRR/NDVI and LANDSAT images
Z. Makhamreha

Theme 2-B: Impacts of climate change on natural resource availability (especially water), agricultural production systems and environmental degradation in dry areas
Co-chairs: Saleh Bader, Jad Isaac

Predicting unmet irrigation water demands due to climate change in the lower Jordan River Basin
M. Haering, Emad Al-Karablieh, A. Salman, H. Gaese & S. Al Quran
Strategic planning for water resources management and agricultural development for drought mitigation in Lebanon
Fadi Karam
Climatic change and wheat rust epidemics: implications to food security in dry areas
Seid Ahmed for Kumarse Nazari, Ram C. Sharma & Abdelhamid Ramdan

Theme 4-B: Mitigation, adaptation and ecosystem resilience strategies including natural resource management and crop improvement
Co-chairs: Calvin O. Qualset, Luigi Guarino

Plant genetic resources management and discovering genes for designing crops resilient to changing climate
S.K. Sharma, I.S. Bisht & A. Sarker
Potential and relevance of dryland agrobiodiversity conservation to adapt to climate change adverse effects
Ahmed Amri et al.
Reviving beneficial genetic diversity in dryland agriculture: a key issue to mitigate climate change negative impact
Reza Hagparast et al.
Conservation and sustainable use of plant genetic resources as a strategy in support of agriculture to achieve food security and promote adaptation to climate change in the Near East and North Africa
Jozef Turok & El Tahir Ibrahim Mohamed
Plant breeding and climate change
Salvatore Ceccarelli et al.
Genotype x environment interaction for durum wheat yield in different climate and water regime conditions in Iran
Reza Mohammadi et al.

Wednesday, 3 February

09.00-10.30 **Plenary session 6**
Co-chairs: Ahmed A. Goueli, Kamel Shideed
Policy and institutional approaches for coping with the impact of climate change on food security in the dry areas of CWANA
Peter Hazell
Rethinking agricultural development of drylands: challenges of climatic changes
Awni Taimeh

11.00-12.30 **Concurrent sessions-C**

Theme 2-C: Impacts of climate change on natural resource availability (especially water), agricultural production systems and environmental degradation in dry areas
Co-chairs: Jose I. Cubero, Zeynal Akbarov

Impact of climate change on diseases of food legumes in the dry areas
Seid Ahmed, Muhammad Imtiaz, Shiv Kumar & Rajinder Malhotra
Implications of climate change on insects: case of cereal and legume crops in North Africa, West and Central Asia
Mustapha Al Bouhssini
Climate change impact on weeds
Barakat Abu Irmaileh
Is climate change driving the indigenous livestock to extinction? A simulation study of Jordan’s indigenous cattle
Raed M. Al-Atiyat

Theme 3-C: Impacts of climate change on food security, livelihoods and poverty
Co-chairs: Hukmatullo Ahmadov, Barbara Rischkowsky

Effect of grazing on range plant community characteristics of landscape depressions in arid pastoral ecosystems
Mounir Louhaichi, F. Ghassali & A.K. Salkini

Theme 4-C: Mitigation, adaptation and ecosystem resilience strategies including natural resource management and crop improvement
Co-chairs: Ahmed Nasser Al-Bakri, GuranAlksidze

Thermo-tolerance studies for barley varieties from arid and temperate regions
Muhammad. N. Shahwani & Peter Dominy
Potential of improving and stabilizing wheat yields in the context of climate change
Mohammed Karrou & O. Abdalla
Breeding food legumes for enhanced drought and heat tolerance to cope with climate change
Muhammad Imtiaz, S. Kumar, F. Maalouf & R. Malhotra
Community-based breeding programs to exploit genetic potential of adapted local sheep breeds in Ethiopia
A. Haile et al.
New feeding strategies for Awassi sheep in drought affected areas and their effect on product quality
M. Hilali, L. Iniguez, H. Mayer, W. Knaus, S. Schreiner, M. Zaklouta & M. Wurzinger

13.30-15.00 Concurrent sessions-D

Theme 4-D: Mitigation, adaptation and ecosystem resilience strategies including natural resource management and crop improvement
Co-chairs: Fawzi Karajeh

Role of soil organic matter and balanced fertilization in combating land degradation and sustaining crop productivity
Anand Swarup

Soil carbon sequestration: can it take the heat of global warming?
Rolf Sommer & Eddy De Pauw
Community-based reuse of gray water in home farming
Abeer Al-Balawenah, Esmat Al-Karadsheh & Manzoor Qadir
Mycorrhizal fungi role in reducing the impact of environmental climate change in arid regions
Ghazi N. Al-Karaki
Breeding durum for climate change in the Mediterranean region
Miloudi Nachit & Jihane Motawaje

Theme 5-D: Policy options and institutional setups to ensure enabling environments to cope with climate change impacts
Chair: Peter Hazell

The impacts of wheat improvement research on poverty reduction in different agroecologies in dry areas
Aden Aw-Hassan, A. Mazid, M. Sayedissa, J. Alwang, S. Kaitibie & G. Norton
Drought mitigation in Salamieh District: technological options and challenges for sustain able development
B. Lalani & M. Ali Al-Zein
Climate change demands refocusing the research agenda for food security in Central Asia and Caucasus
Stefanie Christmann

15.30-16.30 Panel discussion

Moderator: Mahmoud Solh
Panelists: Adel El-Beltagy, Ahmed A. Goueli, Gareth Wyn Jones, J.S. Samra, Mahmoud Duwayri, Peter Hazell

16.30-17.30 **Concluding session & closing**
Co-chairs: Mahmoud Solh, Mohan Saxena

- Discussion and adoption of Amman Declaration
- Closing statements
    - Host Country
    - ICARDA

Thursday, 4 February

09.00-17.00 Field visit to the Jordan Valley and the Dead Sea region

Appendix 3: Conference Committees

Organizing Committee

- H.E. The Minister of Agriculture of Jordan (Co-Chair)
- Dr Mahmoud Solh, Director General, International Center for Agricultural Research in the Dry Areas (ICARDA), Syria (Co-Chair)
- Dr Faisal Awawdeh, Director General, National Center for Agricultural Research and Extension
- (NCARE), Jordan
- Dr Nasri Haddad, Regional Coordinator, West Asia Regional Program, ICARDA, Jordan
- Dr Maarten van Ginkel, Deputy Director General for Research, ICARDA, Syria
- Dr Kamil Shideed, Assistant Director General for International Cooperation and Communication, ICARDA, Syria
- Dr Theib Oweis, Director, Integrated Water and Land Management Program, ICARDA, Syria
- Dr David Hoisington, Deputy Director General, International Crops Research Institute for the Semi Arid Tropics (ICRISAT), India

International Scientific Committee

- Dr Mohan C. Saxena, Senior Advisor to the ICARDA Director General (Chair)
- Dr J.S. Samra, CEO, National Rainfed Area Authority, Ministry of Agriculture, India (Co-Chair)
- Dr Awni Taimeh, Professor of Land Use, University of Jordan (Co-Chair)
- H.E. Dr Mahmoud Duwyari, Professor of Plant Breeding, University of Jordan, Amman, Jordan
- H.E. Dr Muhammad Shatanawi, Professor of Hydraulics and Irrigation Engineering, University of Jordan
- Dr Richard Gareth Wyn Jones, Centre for Arid Zone Studies, University of Wales, UK
- Dr Mahendra Shah, International Institute for Applied Systems Analysis, Laxenburg, Austria
- Dr Donald Wilhite, Director, School of Natural Resources, University of Nebraska, Lincoln, USA
- Dr John Snape, Cereal Geneticist, John Innes Center, UK
- Dr Anwar Battikhi, Soil Physicist, Jordan University for Science and Technology, Jordan
- Dr Atsushi Tsunekawa, Director, Arid Land Research Center (ALRC), Tottori University, Japan
- Dr Faisal Awawdeh, Director General, NCARE, Jordan
- Dr Ayman Abu Hadeed, President, Agricultural Research Center, Egypt
- Dr Maarten van Ginkel, Deputy Director General for Research, ICARDA, Syria
- Dr Theib Oweis, Director, Integrated Water and Land Management Program, ICARDA, Syria
- Dr Eddy De Pauw, Head, GIS Unit, ICARDA, Syria

National Organizing Committee

- Dr Faisal Awawdeh, Director General, NCARE, Jordan (Co-Chair)
- Dr Nasri Haddad, Regional Coordinator, West Asia Regional Program, ICARDA, Jordan (Co-Chair)
- Representatives of:

  Ministry of Agriculture
  Ministry of Water and Irrigation
  Ministry of Environment
  Faculty of Agriculture, University of Jordan
  Faculty of Agriculture, Jordan University of Science and Technology
  Faculty of Agriculture, Balqa Applied University
  Faculty of Agriculture, Mu'tah University
  Higher Council for Science and Technology
  Jordan Badia Research and Development Center
  Jordan Meteorological Department
  Jordan Farmers Union
  Agriculture Engineers Association
  Jordan National Alliance Against Hunger
  Agriculture Credit Corporation

About ICARDA & CGIAR

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is one of 15 centers supported by the CGIAR. ICARDA's mission is to contribute to the improvement of livelihoods of the resource-poor in dry areas by enhancing food security and alleviating poverty through research and partnerships to achieve sustainable increases in agricultural productivity and income, while ensuring the efficient and more equitable use and conservation of natural resources.

ICARDA has a global mandate for the improvement of barley, lentil and faba bean, and serves the non-tropical dry areas for the improvement of on-farm water use efficiency, rangeland and small-ruminant production. In the Central and West Asia and North Africa (CWANA) region, ICARDA contributes to the improvement of bread and durum wheats, kabuli chickpea, pasture and forage legumes, and associated farming systems. It also works on improved land management, diversification of production systems, and value-added crop and livestock products. Social, economic and policy research is an integral component of ICARDA's research to better target poverty and to enhance the uptake and maximize impact of research outputs.

The Consultative Group on International Agricultural Research (CGIAR) is a strategic alliance of countries, international and regional organizations, and private foundations supporting 15 international agricultural Centers that work with national agricultural research systems, and civil society organizations including the private sector. The alliance mobilizes agricultural science to reduce poverty, foster human well being, promote agricultural growth, and protect the environment. The CGIAR generates global public goods that are available to all.

The World Bank, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), and the International Fund for Agricultural Development (IFAD) are cosponsors of the CGIAR. The World Bank provides the CGIAR with a System Office in Washington, DC. A Science Council, with its Secretariat at FAO in Rome, assists the System in the development of its research program.