ICARDA Caravan

Issue No. 25, December 2008

ICARDA

Review of agriculture in the dry areas

Special issue on climate change

History, evolution, and plant breeding

Climate change and water

Carbon sequestration in Central Asia

Local livestock breeds to cope with climate change

Does irrigation contribute to climate change?

... and more

ICARDA Caravan
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From the Director General

Climate change was once a matter for academic debate. Today, it is an accepted reality, and recognized as a major threat to global food security. The impacts will be felt most severely in dry areas, particularly the Near East and sub-Saharan Africa. Agricultural productivity in these regions is already limited by a range of factors: fragile ecosystems, erratic rainfall, frequent drought, land degradation, loss of biodiversity, salinity, temperature extremes, plant diseases, insect pests… Climate change will aggravate each of these problems.

Ever since ICARDA was established in 1977, our research has focused on dry areas, and particularly on helping small-scale farmers cope with climate variability – within a season, and from one season to the next. We are now tackling climate change issues more broadly, with greater emphasis on adaptation, mitigation and ecosystem resilience. ICARDA and its partners have developed a range of technologies and institutional and policy innovations to meet these challenges. Many of these solutions are potentially applicable to other regions beyond the dry areas, where they can help poor rural communities adapt to a changing environment.

This issue of Caravan describes some of ICARDA's work on climate change. It contains overviews of the key issues, and articles describing research in specific areas. We examine, for example, how genetic resources – landrace varieties, wild relatives, indigenous livestock breeds – can be used to make small-scale agriculture better adapted to a changed climate. We discuss the implications of climate change on the evolution and spread of plant pathogens, on policy options for improving rural livelihoods, and on centuries-old patterns of livestock migration. We describe low-cost technologies to improve water management in the face of growing scarcity. We illustrate how remote sensing and geographic information systems can help identify climate change 'hot spots' and analyze long-term changes in the environment. We discuss soil carbon and carbon sequestration in the context of developing-country agriculture. We identify lessons learnt in dry areas in West Africa, that could be put to use elsewhere.

Clearly, ICARDA has played, and will continue to play, a major role in research on climate change adaptation. But we also have another, complementary role as a catalyst and facilitator. The Center has long-standing partnerships with national research programs in every country where we work. We also have close ties with advanced research centers in the Americas, Europe and elsewhere. We are thus ideally positioned to create linkages between institutions in different countries, and facilitate North-South as well as South-South partnerships. Climate change is too large a problem for any one country or one institution to tackle; broad-based partnerships are essential. ICARDA's long experience in building such partnerships will help ensure that countries across the world's dry areas can work together, and effectively use the global knowledge base to address the challenges of climate change.

Mahmoud Solh
Director General, ICARDA

CGIAR Initiative on Climate Change

The CGIAR plans to step up its efforts on climate change mitigation and adaptation, and is urging all partners to increase their investment in research related to climate change. At the CGIAR Annual General Meeting in December, Katherine Sierra, World Bank Vice President for Sustainable Development and Chair of the CGIAR, reiterated the importance of positioning the CGIAR as a center of excellence in adaptation and mitigation research targeted at poor farmers.

The CGIAR has begun the process of developing a strategic initiative on climate change. As a first step the Alliance, Science Council and CGIAR Secretariat will take stock of ongoing and planned work by each Center. A conference will be held in 2008, bringing together scientists from the CGIAR, national research centers, and advanced research institutes worldwide. The conference will help identify research gaps, and priority areas where the CGIAR Centers are best placed to contribute.

Ms Sierra emphasized the need for flexible financing mechanisms and program structures which would enable the CGIAR to develop new initiatives quickly, and highlight more effectively the relevance of CGIAR research to climate change issues.

Retrofitting Civilization for Climate Change

Calvin on climate change: big challenges, but also big opportunities, especially in agriculture and energy.

The 2007 Crawford Memorial Lecture was delivered at the CGIAR Annual General Meeting in Beijing, China, by Dr William Calvin, an eminent theoretical neurobiologist from the University of Washington in Seattle, USA. The Crawford Lecture, named after Sir John Crawford, a founding father of the CGIAR, is sponsored by the Australian government.

Dr Calvin's presentation, 'The Great Use-it-or-lose-it Intelligence Test', provided plenty of food for thought. He explained mankind's tardiness in taking climate change seriously as 'the status quo bias'. He suggested two contributing factors. First, most climate scientists are trained to think in terms of certainty and understatement, not in terms of risk and its management. Second, politicians are unwilling to take hard decisions. These factors, he believes, have left us with a very conservative view of the challenges that climate instability will bring, and what must be done to reduce the impacts.

Following a sobering description of the consequences of inaction, his conclusions were optimistic. Society may, in fact, find the intellectual depth and leadership to make the changes now needed: after all, within the 50,000-year timeframe of the modern mind, periods of enlightenment have been linked to periods of severe climate change or instability.

Dr Calvin highlighted two key areas in the climate change battle: agriculture and energy. "Many of the opportunities to fix our global climate lie in the agricultural sector, because there is so much 'low-hanging fruit' there, irrigation, tillage and fertilizer practices being what they currently are."

In relation to energy, he offered several suggestions: a carbon tax balanced by tax relief to reward those who carpool, insulate their homes and buy clean-fuel vehicles; plug-in hybrid cars; banning new coal plants; cloning nuclear and geothermal power plants; and helping developing countries with solar, thermal or geothermal installations, which run steam plants, in return for binding agreements not to add fossil carbon to the air.

"Thanks to our accumulated intellectual achievements, a Third Industrial Revolution is likely coming, one that will replace fossil fuels and create non-polluting agriculture. The problem, however, is time... Our present civilization is like a magnificent cathedral, back before flying buttresses were retrofitted to stabilize the walls. Civilization now needs such a retrofit and the agricultural research community has a significant role to play."

Climate Change Strategies for Africa and the Mediterranean

The International Solidarity Conference on Climate Change Strategies for African and Mediterranean Regions was held in Tunis, Tunisia, 18-20 November 2007. It focused on climate change issues in relation to energy, infrastructure, natural resources, agriculture and the environment; mitigation and adaptation measures at various levels; partnerships and funding mechanisms; and the process of mainstreaming climate change in development planning. There were 1400 participants including government ministers, climate change experts, and representatives of international and regional organizations, donors, the private sector and civil society organizations.

The conference was opened by Mohamed Ghannouchi, Prime Minister of Tunisia. The speakers included R.K. Pachauri, Nobel Peace Prize winner, IPCC Chairman and President of the World Sustainable Development Forum; and Yvo De Boer, Ahmed Djoghlaf, and Luc Gnacadja, who head the UNFCCC, UNCBD and UNCCD, respectively. Twenty-four ministers and national leaders shared their perceptions on climate change adaptation and mitigation. The program included a ministerial roundtable (involving ministers in charge of climate change issues and representatives of UN agencies and other international and regional organizations), seven parallel workshops on specific technical issues, and plenary sessions.

Discussions on Tunisia-ICARDA collaboration, in parallel to the Tunis conference. Left to right: Abderrazak Daaloul, State Secretary at the Ministry of Agriculture; Mahmoud Solh; and Abdelaziz Mougou, President, IRESA.

ICARDA, which played a major role in organizing the conference, was represented by Director General Mahmoud Solh and other senior scientists. Dr Solh addressed the conference at the opening ceremony; participated in the ministerial roundtable; delivered a keynote paper at the Science and Technology plenary session; and chaired a workshop on 'Tools to integrate adaptation in development'.

Two major outputs were achieved at the conference: a Tunis Declaration (see box), agreeing on a common regional input for the Bali meeting, and an action plan on an integrated climate change strategy for Africa and the Mediterranean.

Tunis Declaration (an extract)

Governments, multilateral and bilateral organizations, corporates, NGOs and academics at the Tunis Conference declare that they will:

- Endeavor to incorporate climate change adaptation within development strategies.
- Strive to ensure that developing countries in Africa and the Mediterranean region are capable of reducing their vulnerability to climate change, defining national adaptation strategies, and integrating adaptation measures within national and sector-based projects.
- Develop capacity and the necessary structures, at all levels, for elaborating and implementing climate change adaptation strategies.
- Reinforce capacities for public information and sensitization about the effects of climate change, and ensure their incorporation within adaptation and mitigation programs.
- Implement programs to transfer information and technologies to elaborate national development strategies.
- Strengthen expertise, cooperation and solidarity for prevention of and action against climatic extremes in the most vulnerable countries.
- Endeavor to promote renewable energies and energy efficiency in all sectors.
- Reinforce South-South and North-South cooperation and promote information exchange.
- Develop more efficient mechanisms of cooperation and support in order to enhance climate change adaptation efforts in Africa.
- Seek to mobilize the necessary financial resources for establishing attenuation and adaptation strategies and plans of action.

Science Week focuses on climate change

ICARDA Science Week, held in October 2008, focused on climate change. The aim was to review ongoing work, and plan future research on climate change adaptation and mitigation. In addition to ICARDA scientists, three guest speakers were invited: Mahendra Shah from the International Institute for Applied Systems Analysis, Austria; Ross Kingwell from the Western Australian Department of Agriculture and Food; and Delia Grace from the International Livestock Research Institute, Kenya.

Dr Kingwell discussed the Australian experience. Climate change will impact significantly on the country's main farming areas. We need not only new farm technologies suited to a changed climate, but also a better understanding of how changes in national (and international) policy will affect farm output and profitability. Dr Shah noted that scientists and policy makers have focused largely on climate change mitigation. Too little attention has been paid to adaptation – a critical issue in developing countries. He suggested that ICARDA could help identify specific crops and resource management technologies suitable for specific production systems, and generate data to support national policy development. Dr Grace described how climate change could accelerate the emergence and spread of animal diseases. The impacts would be severe, given the importance of livestock as a 'livelihood stabilizer' under variable climatic conditions.

Presentations by ICARDA scientists highlighted a number of successful technologies and research methods, developed or adapted by ICARDA and its partners, that we will continue to build on.

New tools for new science

- GIS-based methods to scale down global climate model predictions and target interventions more effectively; tools to assess climatic risk and assist adaptation at local level.
- Genomic technologies in breeding for adaptation to climate change: use of wild relatives to improve drought tolerance, genetic and physiological dissection of adaptive traits.
- A simple model to assess the effect of climate variability on water resources. If supported with regular monitoring, it can help reduce uncertainties caused by climate change.
- Methodologies to identify vulnerable communities and households, and analyze household decision making processes in the context of climate change.

Crops and farming systems

- Pro-active resistance breeding against a parasitic weed that is expanding rapidly as a result of climate change.

Science Week: climate change adaptation will be a key part of ICARDA's research agenda.

- Agro-ecological zoning to maximize benefits from changes in crops and cropping patterns driven by climate change.
- Pest control and climate change: monitoring insect pests and their natural enemies, developing low-cost, environment-friendly management strategies.
- Exploiting physiological factors (e.g. plant source-sink relationships) to design technologies to reduce drought effects and improve water-use efficiency.

Natural resources and livelihoods

- Economics: optimization of all input use (water, labor, fertilizer etc) in a holistic framework. This becomes critical as farmers modify their input-use decisions in response to greater variability.
- Research priorities for rangeland areas: climate-risk insurance, local climate models, pastoral species capable of auto-regeneration.
- Broadening livelihood options: greenhouse production and hydroponics to produce high-value crops. This substantially increases farm income as well as water-use productivity.
- Soil carbon sequestration: quantitative estimates for Central Asia, and implications for mitigation.

Each presentation was followed by intensive discussions that helped clarify technical issues, identify knowledge gaps, and identify potential research partners. Summing up, Dr Solh said: "We chose climate change as the theme for Science Week because farmers in our mandate region are particularly vulnerable. I think we made the right choice, and that we are now better positioned to contribute to global efforts to fight the effects of climate change."

Helping Farmers Cope with Climate Change

Feeling the heat? Protecting subsistence farmers from the worst impacts of climate change.

Richard Thomas

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), published in 2007, leaves no doubt that the Earth's climate is changing, largely as a result of human activity. The last 60 years were the warmest in the last 1000 years. Rainfall patterns are changing. Both floods and droughts are becoming more frequent, and more severe. The impacts will be felt worldwide, but nowhere more acutely than in the world's drylands. Drylands will face not only higher temperatures, but more importantly, disruptions to their hydrological cycles resulting in lower and more erratic rainfall, exacerbating already critical levels of water scarcity and fanning conflicts over water allocation. For example, Mediterranean Africa is likely to lose up to 20% of its current water supplies by the year 2100, with hotter summers, lower rainfall, and increased likelihood of summer droughts.

The rural poor in dry areas will require a range of strategies to cope with climate change. These strategies will include new crops and varieties with better drought and heat tolerance; switching from cereal-based to cereal-legume systems; more diverse farming systems that produce higher value outputs; more efficient use of water; and conservation agriculture methods to reduce soil erosion. New pest management methods will be required as changes in climate cause changes in the geographic distribution and spread of disease vectors. Another challenge is to 'intrapolate' global climate models to national or even sub-national scale, to provide early warnings and risk estimates of droughts or floods.

Adaptation plus mitigation

In the context of agriculture, solutions to climate change involve two aspects: adaptation (how to maintain production under the changed conditions) and mitigation (how to soften the impacts on the most vulnerable communities). ICARDA's research contributes to both aspects. The table on page 7 provides an outline of how our work relates to climate change. Other articles in this issue describe some of the results already achieved, and lessons learnt for the future.

Clearly, better adaptation will require new technologies. But technology alone isn't enough. To reduce vulnerability to climate change, we need to tailor development efforts to local conditions, with a clear understanding of the social and economic factors (property rights, markets, local institutions etc) that determine land use practices. ICARDA scientists have studied these factors in different countries for many years, and the results will help develop strategies that are practical and relevant to poor dryland communities.

How can ICARDA help?

Some climate change is inevitable. Can we find ways to help the most vulnerable communities adapt to or cope with the impacts? To do this, we first need to:

- Assess current conditions (e.g. land use, vegetation cover) and where possible, measure how these have changed over time, using remote sensing and ground truthing.
- Better understand the interplay of climatic and socio-economic factors that cause productivity loss and land degradation.
- Assess the risks of climate variability and long-term changes using seasonal and longer-term forecasting linked to agricultural activities and insurance schemes for the rural poor.
- Develop legal and policy frameworks and incentives to support development efforts that link land degradation with climate change adaptation.
- Develop low-cost tools to monitor, evaluate and model land degradation and environmental services. These tools will help land users and policy makers make decisions, and assist regulatory agencies monitor compliance (soil organic matter, carbon sequestration and water quality).
- Build the capacity of communities to adapt to climate risk and reduce land degradation, by linking them with agencies that provide meteorological, hydrological and agricultural services.

Payment for environmental services from rangelands

Rangelands occupy over two-thirds of the world's drylands (828 million hectares in WANA alone). They are used mainly by poor migrant pastoralists, but they provide vital environmental services to millions of people outside the rangelands – nutrient cycling, water purification and supply regulation, pollution filtration, carbon sequestration, biodiversity protection, erosion control. Pastoralists will be hit hard by climate change. More droughts and less vegetation will lead to changes in the patterns of animal movements and probably accelerate rangeland degradation, reducing the capacity of rangeland systems to provide environmental services.

One solution – payment for environmental services. Recipients of these services, or agencies acting on their behalf, pay pastoralists to conserve the rangelands, and thus maintain environmental services. ICARDA has initiated a study that will examine the feasibility of this concept, implementation problems (e.g. who pays whom, and how), and how to put a value on environmental services.

Two-thirds of the world's dry areas are occupied by rangelands; and more than half of these rangelands are degraded.

Several of ICARDA's current research projects relate to climate change and variability. These projects focus on technological, marketing, policy and institutional options for adaptation and mitiga-

ICARDA and climate change: research projects for mitigation, adaptation and ecosystem resilience

Research activity	Ecosystem resilience	Mitigation of climate change	Adaptation to climate change
Conservation, characterization and sustainable use of genetic diversity. New varieties with better tolerance to abiotic stresses (extreme temperatures, droughts, flooding, salinity)	Understanding of functional biodiversity and 'keystone' species will help maintain ecosystem functions and resilience	Increased C sequestration, lower GHG emissions from farms and natural habitats. In situ conservation of biodiversity	Better targeting of germplasm to specific environments
Collection and use of commercially promising and/or under-utilized plants	More efficient water use		Introduction of new commercial species with low water requirements, to broaden livelihood options
Dynamics of pests and diseases under a changing climate; crop improvement for biotic stresses	Less reliance on pesticides and herbicides	IPM options will reduce vulnerability to changes in pathogen distribution	Better control, improved prediction of pest and disease infestations
Role of livestock and rangelands in buffering climate change	Less overgrazing, more sustainable extraction	Increased C sequestration in rangeland soils and biomass	Better drought preparedness
Diversification of livelihoods, including new crop-livestock options	More sustainable production systems	Increased C sequestration, reduced GHG emissions	Wide range of production system options
Conservation agriculture and crop rotations	More robust cropping systems will conserve natural resource base	Increased C sequestration, lower energy requirements	Wide range of production system options
Improved water-use efficiency and water allocation	Conservation of water resources will help maintain environmental services	Lower GHG emissions from soils	Production systems adapted to climate variability, especially water scarcity
Water quality monitoring, improved management of marginal-quality water (treated wastewater, saline water)	More sustainable water use, maintenance of environmental services	Increased biomass production and C sequestration	Production systems sustained despite greater use of marginal-quality water
Improved soil management and soil fertility	Increased soil organic matter will increase agro-ecosystem resilience	Increased soil C sequestration	Higher soil organic matter will reduce risk of crop failure from floods, drought
Amelioration and management of salt-affected soils	Salinity mitigation will improve productivity and ecosystem health	Increased soil C sequestration	Amelioration will increase crop productivity, slow down loss of arable land, and in some cases restore productivity of degraded soils
Policy and socio-economic aspects of co-management of water resources		Enabling environment for more sustainable production practices	Enabling environment for more sustainable production practices, wider adoption of improved technologies
Studying local coping strategies, drawing lessons for application to other areas			Wider range of adaptation strategies for resource-poor land users
Understanding trade-offs between development and climate change	Improved ecosystem management		Improved ecosystem management for long term sustainability
Identifying hot spots most vulnerable (food security, poverty, environmental sustainability) to climate change	Improved decision making on crop management based on better and more widely available climate information	Better matching of adapted germplasm to climate variability. Lower GHG emissions	Adaptation strategies focused on most vulnerable regions. Improved climate information used to refine coping/adaptation strategies

tion, drawing on results from the Center's work for 30 years in dryland areas on four continents. Other projects, now being planned, will:

- Help make climate change information more relevant and usable for land users and decision makers.
- Develop climate risk screening tools to help identify which areas are most vulnerable, and how to integrate climate change adaptation into land planning, infrastructure design (e.g. optimizing water capture for a given set of conditions) and agricultural policy.

Small-scale farmers in marginal areas are already struggling. Climate change could force millions off their land.

Perhaps ICARDA's biggest strengths, given the scale and interconnectedness of climate change issues, are its international presence and strong relationships with national research centers and development agencies throughout the world's dry areas. For example, ICARDA can play a key role in sharing best practices, coordinating multi-country, multi-institution programs, and acting as a bridge between local, regional, national and international efforts, in order to assist national agencies develop and implement action programs on climate change.

Focusing on drylands

Drylands have long been neglected by policy makers because they were misperceived as being degraded marginal areas, offering poor returns on development investment. But they are now attracting growing interest from politicians and policy makers, for various reasons – their sheer size (41% of the world's land area), their importance to development objectives (poverty reduction is a key UN Millennium Development Goal; and according to the Millennium Ecosystem Assessment, poverty is greatest in dryland populations), their role in food security (drylands produce the bulk of national food supplies in many countries), and finally their vast potential to sequester carbon, mitigate greenhouse gas emissions and make ecosystems more resilient to further climate shocks.

ICARDA and its partners are building on decades of successful research to help dryland communities not only realize their agricultural potential, but also contribute to global efforts to mitigate the impacts of climate change.

Severe gully erosion, caused by loss of vegetation and uncontrolled runoff. Degradation, already a worldwide problem, could increase dramatically in the next two decades.

Richard Thomas (r.thomas@cgiar.org) has studied desertification and land degradation in dryland areas for over 20 years. He was formerly head of ICARDA's land management research program, and is now Asst. Director (Drylands Program) at UNU-INWEH, Japan.

Breeding Crops
for a Changing Climate

How do plant breeders adapt to climate change? What challenges do they face? How are research programs evolving?

Richard Brettell

Climate change brings many challenges for the plant breeder. Once, it may have been sufficient to develop varieties well adapted to a particular geographical region, taking into account the well understood constraints of disease and end-product quality. Now, the breeder has to consider, in addition, how the variety will perform in an environment with higher levels of carbon dioxide and greater variability in temperature and water availability. Tomorrow's varieties must be able to withstand conditions that are not only hotter or drier, but also more variable. To understand the task that breeders face, it is useful to examine each of the major constraints in turn.

1. Water

Many parts of the world, particularly Central Asia, West Asia and North Africa, are severely limited by the scarcity of water. The quick and easy solution that is usually proposed – breed for drought tolerance – is not as simple as it sounds. There is a direct relation between the amount of water that a plant uses and how much grain or biomass it can produce. If 'drought tolerance' means solely an ability to survive dry conditions, it will not necessarily benefit the farmer, particularly if the drought-tolerant line, in seasons when water is plentiful, gives lower yields than currently available varieties. Even in marginal or drought-prone areas, farmers depend on their crops performing well in the good years. What breeders can do, however, is ensure that their varieties are adaptable: able to perform in difficult environments (for example, with vigorous root systems that can capture scarce water), and also able to produce reasonable yields when conditions are more favorable.

Another example, proving to be effective in cereals, is to breed for long coleoptiles (the pointed protective sheath that covers the emerging shoot). This improves establishment as well as emergence: when seeds are planted deep, the young shoot can break through the soil surface more easily; and plants form a denser, healthier stand. Another is to have roots that can withstand attack by soil-borne pests and diseases.

2. Heat

Climate change will probably result in higher mean temperatures in most parts of the world. Crops will be exposed to higher temperatures at every stage of growth, from seedling establishment to maturity. In colder regions this could mean that crops could be planted earlier in the season, which in turn might require varieties with slightly different phenology, for instance altered sensitivity to changes in daylength.

In regions where temperatures rise steadily over the growing season, the crop may be exposed to very high temperatures at the critical stages of flowering and seed development. Heat-sensitive cultivars may be rendered sterile if exposed to hot conditions (above 35°C) at flowering time. Breeding for heat tolerance is well established, and a range of varieties has been developed for hot regions such as the Sudan and central India.

3. Carbon dioxide

Rising CO_2 levels are considered a precursor of climate change. CO_2 itself is the starting point for carbon fixation by the process of photosynthesis. We know from controlled-environment experiments that photosynthetic performance is actually enhanced by higher levels of CO_2 in the atmosphere.

Plants grow better at higher CO_2 concentrations, because of the way the stomata operate. Stomata (meaning 'mouth' in Greek) are structures on the underside of leaves, consisting of guard cells surrounding a tiny pore. The pore allows gases (CO_2, water vapor, oxygen) to move into and out of the leaf; pore diameter is controlled by the guard cells. When CO_2 levels are higher, the pores need to be open less wide, and consequently the plant loses less water for a given amount of CO_2 taken up.

What is less clear is how this relates to growth and performance under field conditions. Field experiments have been set up in several countries to examine the effects of elevated CO_2 during the cropping season; the approach is known as FACE (Free Air CO_2 Enrichment). The general trend is that higher levels of CO_2 produce slightly higher yield, but different varieties may respond very differently. Also, the beneficial effects of higher CO_2 appear to be muted in drier environments. Current models predict that elevated CO_2 may mitigate, but not overcome, the negative effects of higher temperatures and reduced water availability.

4. Pests and diseases

Pests and diseases present a major unknown when we

Larger root systems usually mean better drought tolerance. Experiments at ICARDA measure root development and plant response to different levels of water stress.

Global warming: good for pathogens?

Climate change could have far-reaching consequences on crop diseases and insect pests – faster-growing pest populations, new pathogen strains, spread of pests and diseases to new areas. For example, many insect pests develop faster, producing more generations per year, at higher temperatures. This means pest populations will grow faster. In addition, host exposure to more pest lifecycles per season will increase the chances for the development of virulent biotypes – which means resistant varieties could have shorter 'life spans'. High temperatures can also affect the expression of resistance genes. Some become ineffective above a 'threshold' temperature; a small minority work better at higher temperatures.

ICARDA's scientists are studying the mechanisms involved, in order to develop varieties that will remain productive and pest- and disease-resistant despite climate change. For instance, our studies on the notorious Hessian fly have shown that some resistance genes in wheat lose their effectiveness at temperatures above 24°C. This has major implications for food security in large parts of North Africa, where the fly is endemic.

Another example is a fungus known as *Puccinia striiformis*, which causes yellow rust disease in wheat. Strains of the fungus have spread across parts of North America, Australia and Europe in less than 3 years – perhaps the fastest ever spread of a major crop pathogen. A collaborative study provided insights on the mechanisms and sequence of dispersal, and the virulence of (and relationships between) different pathotypes. Some of the new strains are far more aggressive than earlier strains, and infect crops in areas once considered too warm or too dry to be vulnerable.

Stem rust – coming soon, to a field near you.

Hessian fly – many currently resistant varieties could become vulnerable.

But the effects of climate change are rarely straightforward. Higher temperatures and lower rainfall will increase soil temperatures, and therefore increase the incidence of soilborne diseases. They also favor many weed species, whose competitive advantage over crop plants is heightened under harsh conditions. On the other hand, hotter, drier conditions disfavor the development of many fungi, so fungal diseases (e.g. most leaf diseases) could reduce. But climate change also alters rainfall patterns: more frequent late-season rains, for example, increases the incidence and severity of some fungal diseases such as ascochyta blight in chickpea (see page 48) and fusarium blight in wheat.

Over the years, ICARDA scientists have developed Integrated Pest Management (IPM) packages for various pests and diseases. We will now need to revisit these packages, to take account of climate change. The Center will work with national research centers as well as specialized laboratories in the West, to:

- Monitor disease/pest damage, and pathogen/insect populations, to understand the effect of climatic changes as they occur.
- Develop computer models to predict disease epidemics and insect population cycles.
- Study how temperature affects the expression of resistance genes (and development of virulent pathotypes/biotypes), to identify which genes are stable at high temperatures.

consider the effects of climate change on agricultural production. Some insect pests may be favored by higher temperatures; some could expand their range into areas where they were previously not found. One example is the Hessian fly. It is currently a major pest of wheat in North Africa. With climate change, it could threaten wheat production in central and southern Europe as well.

The same holds true for fungal pathogens. A pathogen may exist in a given environment but will not cause severe crop damage unless its specific requirements of temperature and humidity are met. For instance, stem rust of wheat tends to be favored by hot, dry conditions. One virulent race of stem rust, known as Ug99 (because it was first reported from Uganda in 1999), has recently been reported from two provinces in a cooler part of Iran, which were earlier free from stem rust. Another example is a parasitic weed known as broomrape or *Orobanche*. It has appeared in Ethiopia, where it had not been reported for at least 50 years. In Egypt, it has spread from hot areas in the interior (around Giza) to the coast.

Adapting to climate change

ICARDA's plant breeders have been outstandingly successful in the past. But the challenges of climate change will require even greater effort, because of the scale and complexities of the processes involved. Correspondingly, our research portfolio now has a much greater emphasis on climate change adaptation. For example in lentil, we are looking at ways to adjust planting time to ensure that critical crop stages (e.g. flowering) do not coincide with unfavorable conditions. In chickpea, we have developed varieties that can be planted in winter, rather than spring. This significantly increases yields, allows the crop to escape end-of-season drought and minimizes the temperature effects of climate change.

Beauty or the beast? Orobanche, or broomrape, is the most damaging weed in dry areas throughout West Asia and North Africa.

In chickpea and faba bean, we're building on the inherent drought tolerance of these species to develop advanced breeding populations, the 'raw material' for new varieties. Also in faba bean, we are screening a wide range of material for Orobanche resistance and heat and drought tolerance, in order to develop varieties that combine all three traits.

In barley we are developing varieties that mature earlier, and thus escape drought – which is expected to become increasingly frequent in most barley production areas worldwide. In bread wheat – the staple food of one-third of the world's population – we are using a combination of conventional breeding methods and biotechnology to improve heat and drought tolerance.

Climate change will affect not only physical conditions in a cropping system, but also upset the delicate balance between the system's components. Clearly, plant breeders' lives will become a lot harder. They will need to be as adaptable as the crops they are breeding, to ensure that the world's food production can be maintained in a changing environment.

Richard Brettell is Director of ICARDA's Biodiversity and Integrated Gene Management Program. He has spent over 30 years in agricultural research, specializing in cereal genetics, in Australia, Switzerland, the UK and West Asia.

History, Evolution, and Plant Breeding:
the Lessons for Climate Adaptation

Salvatore Ceccarelli

For millions of years, plants and animals have adapted – or sometimes failed to adapt – to temperature and CO_2 fluctuations. What lessons does evolution provide?

Will global climate change cause global hunger? Not quite, but it will affect food production as well as food quality, and most developing countries will be hit hard. One prediction, made by Francesco Tubiello and Gunther Fischer in a 2007 paper: between 1990 and 2080, the number of undernourished people will triple in sub-Saharan Africa, and increase by 50% in the Middle East and North Africa. Clearly, it is vital to develop crops and varieties that will be better adapted to the new climatic conditions. To do this we need to understand how crops respond to various changes – higher CO_2 levels, lower rainfall, more extreme events, more variability.

From the results provided by climate models, what should plant breeders expect to face?

- Higher temperatures (almost certain) will reduce crop productivity
- Higher CO_2 concentrations (almost certain) will have both direct and indirect effects
- More frequent drought, increase in the area affected by salinity, increased frequency, incidence and severity of biotic stress.

Consider first the hottest topic of them all – carbon dioxide. We understand fairly well how plants respond to increases in CO_2 concentration, which has both direct and indirect effects.

Direct effects, also known as CO_2 fertilization effects, are caused by the presence of CO_2 in ambient air, and are quite different for C3 and C4 type plants (see box). For C3 plants like wheat and barley, current atmospheric CO_2 levels are sub-optimal. Higher levels will increase photosynthetic rate, reduce transpiration rate (by reducing stomatal conductance), improve the plant's water-use efficiency, and therefore reduce the probability that crops will suffer water stress. As a consequence, crop growth and biomass production should increase significantly.

Doubling the ambient CO_2 level would increase biomass production by 10-30% (results from different studies). In theory, at 25°C, an

Three carbons or four?

The terms C3 and C4 refer to two kinds of photosynthesis, used by two different groups of plants. They are so named because the first stable compounds formed after CO_2 is 'fixed' during photosynthesis, contain 3 and 4 carbon atoms in C3 and C4 plants, respectively.

C3 plants evolved first, and represent over 90% of the world's plant species, including wheat, barley, rice, potatoes and most trees. They are temperate plants. C4 plants evolved millions of years later, in response to changing conditions – lower water availability, higher temperatures and lower levels of atmospheric CO_2. They represent around 1% of plant species (including maize, sorghum and sugarcane), but account for about 30% of terrestrial carbon fixation. They are found mainly in the tropics.

- C3 plants lose 97% of the water taken up through their roots to transpiration. Under temperate conditions they are more efficient than C4 plants. But they are sensitive to high temperatures and drought, so yields of most crops, in most areas, could fall as a result of climate change.

- C4 plants absorb CO_2 much faster and more efficiently (losing less water per unit of CO_2 absorbed) than C3 plants. Typically, they produce about 50% more biomass than C3 plants. C4 plants will be affected by climate change not directly but indirectly, through greater competition from C3 weeds.

Displaying diversity. All these crops (and several others, not shown) were harvested from a single small-scale farm in Cuba.

increase in CO_2 from the current 385 ppm to 550 ppm, projected for the year 2050, would increase photosynthesis by 38% in C3 plants. In C4 plants, for which current CO_2 levels are optimal, an increase in water-use efficiency (by a reduction in stomatal conductance) may still increase yield.

The indirect effects of CO_2 (weather effects) relate to solar radiation, precipitation and air temperature. If crop management is unchanged, yields of cereal crops typically decrease with increasing temperatures and increase with increased solar radiation.

The combined direct and indirect effects will be highly negative. Agricultural production is expected to increase by about 5% at high latitudes (above 40 degrees). But at lower latitudes – where the vast majority of the world's poor live – production will fall by 20 to 40%.

Less diverse, more vulnerable

The potential impact of climatic changes could be magnified by the progressive loss of crop diversity over the past 150-200 years, particularly in developed countries. The world has roughly 250,000 plant species, of which about 50,000 are edible. We actually use no more than 250 – out of which 15 crops supply 90% of the calories in the human diet, with 3 of them (wheat, rice and maize) accounting for 60%. In these three crops, modern plant breeding has dramatically increased yield and output, but reduced genetic diversity. The most widely grown varieties of these three crops are closely related and essentially genetically uniform (hybrids in maize, pure lines in wheat and rice). Consequently, our main sources of food are genetically more vulnerable than ever. The danger to global food security is real – consider, for example, the rapid spread of disease pathogens such as Ug99 (see page 11).

But there is another, less visible problem. In a diverse, heterogeneous system (diverse crops and diverse varieties of each crop), individual plants can adapt to new environmental conditions. Gradually, populations (groups of plants, which will later become varieties) can evolve. In the current homogeneous system, this ability is being lost.

With a little help from Darwin…

Plant breeders have various strategies to cope with climate change. One is to develop varieties suited to a shorter crop season, by matching phenology to moisture availability, i.e. modifying the growth cycle to ensure that plants have sufficient moisture during the critical stages. This should not pose major problems because the response of a plant to changes in photoperiod (daylength) and temperature is well understood, governed by specific genes, and is highly heritable, i.e. a 'good' plant's traits can be transferred to its progeny.

Another strategy is to develop not a single variety but a suite of varieties ranging from early- to late-maturing: fields are planted with a mixture, so that the harvest is less vulnerable to stress at critical periods in the crop cycle. Another is to shift the temperature optima for crop growth. Yet another is to re-emphasize population breeding, as opposed to pure line breeding.

In all cases the emphasis should be on using genetic variation – from the diverse genetic material available, identify sources of tolerance/resistance to abiotic stresses, and use these sources to combat the effects of climate change. There are two obvious places to look for genetic variation – genebanks and farmers' fields. ICARDA has one of the world's largest genebanks, with over 110,000 accessions of important food and forage crops; and is involved in several international projects to identify genes associated with heat and drought tolerance. We know that landraces (traditional varieties grown by farmers) as well as their wild relatives harbor a large amount of genetic variation, some of which can be put to immediate use in breeding programs.

There is one major difference between the two sources of genetic variation. The diversity stored in genebanks is static – it represents the variation available at the collection sites at the time the collection was made. Diversity in farmers' fields is dynamic – landraces and wild relatives are heterogeneous populations, continuously evolving and generating more variation.

ICARDA has begun an 'evolutionary' breeding program in Syria, Jordan, Iran and Algeria. The aim is to increase the probability of recombination within a population which is deliberately constituted to harbor a very large amount of genetic variation. This population will include hundreds of F2 plants (the stage at which genetic differences first become apparent). It is planted at multiple locations and left to evolve, on its own, under the pressure of changing climatic conditions. While the population is evolving, breeders

Evolutionary breeding. Ongoing evolution within a diverse population will provide farmers and plant breeders with a continuous flow of better adapted genetic material.

Climate change – millions of years ago

Climate change is not a recent phenomenon. It is, in fact, as old as the earth. Several cycles of climate change have occurred before, with dramatic consequences. The first took place some 350 million years ago. Atmospheric CO_2 levels, which were then 15 times as high as today's levels, fell significantly – and as a result, plant leaves evolved. At very high CO_2 levels, plants were able to absorb enough CO_2 through their stems. At lower concentrations, they needed a different structure – leaves. The first plants were leafless; it took 40-50 million years for leaves to appear.

The second major event occurred in Siberia 250 million years ago, when a series of gigantic volcanic eruptions spewed an estimated 4 million cubic kilometers of lava onto the earth's surface. The eruptions caused, directly or indirectly, a worldwide depletion of the ozone layer and a consequent spike in the amount of ultraviolet radiation reaching the earth's surface. This explains why the peak phase of eruptions coincided with a mass extinction that wiped out 95% of the world's species.

The third major climatic change was the end of the Ice Age, between 13,000 and 11,500 BC. Much of the earth became subject to long dry seasons. This created favorable conditions for annual plants, which can survive the dry season either as dormant seeds or as tubers. Eventually agriculture began, around 9000 BC; first in the Fertile Crescent of the Near East, and soon after, independently, in other areas.

The fourth climatic change was the so-called Holocene flooding which occurred about 9000 years ago and is believed to be associated with the final collapse of the ice sheet that covered large parts of the world (the ice was up to 3 km thick in parts of North America). As the ice melted, global sea level rose by up to 1.4 meters, swallowing up land, forcing animal species to mass-migrate to higher ground. This could explain how domesticated plants and animals, which by then had already reached modern Greece, began moving north-west towards the Balkans and other parts of Europe.

and farmers visit the plots, and use their own selection criteria (yield, taste, disease resistance etc) to select specific plants. This sub-population can then be grown by farmers, or used by breeders to develop 'pure lines' for further testing. But the long-term benefit is that the main population continues to evolve, becoming a unique source of continuously better adapted genetic material not only for today's farmers but also for their children.

The concept of evolutionary plant breeding is not new. What is unique about ICARDA's approach is that it builds on participatory plant breeding (PPB) programs, pioneered by ICARDA, that have been successful in several countries. In PPB, trials are planted in farmers' fields, and breeders and farmers work together to test and select varieties. The 'evolutionary' breeding program will be implemented in communities that are already familiar with PPB, and therefore have the skills to make the best use of genetic variation.


SALVATORE CECCARELLI

Participation is the key. Researchers and farmers work together to test and select varieties that best suit local conditions and farmers' priorities.

Salvatore Ceccarelli (s.ceccarelli@cgiar.org) has been a plant breeder for over 40 years, working in West Asia, North Africa, Europe, and the Americas. He has developed nearly 100 new barley varieties for marginal environments, and pioneered farmer-participatory methods that are redefining research approaches in West Asia and elsewhere.

Climate Change and Water:

the Challenges for Dry Areas

Simple, low-cost technologies are helping to use scarce water more efficiently, fight erosion – and even rehabilitate degraded land.

Mohammed Karrou and Theib Oweis

Climate change is expected to have severe global impacts. Most parts of the planet will be affected – particularly the dry areas, where existing problems of climate variability, drought and temperature extremes will be exacerbated. The CWANA region (Central and West Asia, North Africa) constitutes a large proportion of the world's dry areas. ICARDA's research in the region provides valuable lessons, and a framework for R&D efforts to help the world adapt to climate change.

Most CWANA countries are already very dry, with low (100-500 mm per year) and erratic rainfall, and high temperatures during much of the summer cropping season. Climate models predict even lower rainfall and more frequent, more intense droughts. Droughts have become measurably more frequent in the last three decades, causing periodic food shortages. The region's population has grown from 125 million in the 1970s to 280 million plus in 2000, and is expected to reach over 400 million by 2030. This has put increasing pressure on already scarce natural resources. The scarcest of these resources is water.

Lower and more erratic rainfall will affect not only crops but also river flows and groundwater recharge. Water shortages will grow, creating conflicts between different groups of users, such as farmers, urban households, and industry. To better understand the potential impacts, we first look at the three broad agro-ecologies in the CWANA region – rainfed systems, irrigated systems, and rangelands.

Rainfed systems

Over 60% of the region's food is grown in rainfed agro-ecosystems. Yields are poor and crop failures frequent, because rainfall is low and poorly distributed, with long dry spells during which soil moisture is too low for crop plants to survive. Climate change will greatly increase these stresses: lower and more erratic rainfall, shorter growing seasons, more erosion, and more water loss through evaporation.

But solutions are available, some of which are being successfully used in several countries. These include supplemental irrigation, water harvesting, drought-tolerant varieties, new crops and crop sequences, and low-cost methods to improve land and water management. Along with these technologies, we will also need new policies and local regulations to allocate scarce water more efficiently.

Irrigated systems

Irrigated areas face two kinds of problems – water availability and water quality – and both will be exacerbated by climate change. Irrigation now consumes over 80% of the region's river and aquifer water. The availability of irrigation water will inevitably decline as a result of climate change and because of increasing demand from non-agricultural users. As availability declines, more marginal-quality water (saline water, treated sewage water) will be used for irrigation, with potential impacts on soil health.

Desert blooms, subject of a recent PhD study. Jordan's dry rangelands are home to several hundred species of shrubs and flowering plants, adapted to dry and variable conditions.

Potential solutions must therefore address both aspects. Irrigation methods that increase water-use efficiency (e.g. sprinkler and drip irrigation) must be encouraged, in combination with improved irrigation scheduling (e.g. deficit irrigation), new cropping patterns, and better crop and soil management, to compensate for lower irrigation amounts. Drainage systems and irrigation methods will need to be modified to cope with declining water quality.

Rangelands

Rangelands or steppe areas (*badia*, in Arabic) occupy over half of CWANA. These are typically degraded areas with very low rainfall (below 250 mm), prone to desertification, caused by natural processes like runoff and erosion, as well as human and livestock activity. Climate change will accelerate this decline, with more intense storms, higher runoff rates, more erosion, declining productivity, and further depletion of groundwater. Simultaneously, the pressure on rangelands will increase, as human and animal populations and demand for livestock products increase – leading to further degradation.

To cope with climate change, we will need a better understanding of the system dynamics, new policies to reduce human pressure on rangeland ecosystems, controlled grazing to maintain vegetation health, and an integrated approach (centered on water harvesting) to rehabilitate degraded areas.

Research for better adaptation

In 2007, ICARDA launched a new strategic plan to guide our research over the next decade. Climate change adaptation is a 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.
- Building partnerships with other institutions to test and promote new technologies.

Some of this work is described elsewhere in this issue. Here we focus on technologies related to water, and its efficient use under scarcity conditions.

Drought mitigation

ICARDA, working with research centers in the Mediterranean region, has helped develop a decision support system to mitigate the effects of drought. The main goal was to improve the management of irrigation systems under drought conditions. Subsequently, we worked with CIHEAM, FAO and other partners to establish the Near East, Mediterranean and Central Asia (NEMEDCA) Drought Network. The network enables institutions in 38 countries to exchange information, participate in workshops and training programs, and share experiences on how to predict and respond to drought. Building on these activities, we were part of the European Union's Medroplan project led by CIHEAM. The project developed a set of guidelines to help governments develop drought risk management plans. The aim was to replace the usual short-term reactive measures with a pro-active approach centered on evaluating and managing risk.

Micro-catchments trap runoff water, providing a favorable environment for shrubs. Result: less erosion, more fodder for animals.

Supplemental irrigation

Many farmers in the dry areas use full irrigation, i.e. supplying enough water to meet (and often exceed) the crop's requirements during the summer. A far more efficient practice is supplemental irrigation: limited irrigation for otherwise rainfed crops, carefully timed to avoid water stress during critical stages, e.g. when plants are flowering or filling grain. Supplemental irrigation, combined with rainfall, not only stabilizes crop yields but also significantly increases water productivity, i.e. the quantity of grain or biomass produced per unit of water.

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. At a project site in Tadla, Morocco, we're studying and demonstrating a combination package for wheat – early planting with a little supplemental irrigation in the spring.

Supplemental irrigation can increase water productivity by 150%, as demonstrated in on-farm trials in Morocco.

The package doubled yield and water productivity, and ensured that plants escaped the drought and heat stress that frequently occurs in the final weeks of the season.

The interaction between high CO_2 levels, high temperature and water deficit – which will all become increasingly important with climate change – is not well understood, partly because it's difficult to study in the field. ICARDA is using simulation modeling to understand these relationships, specifically to measure the effect of supplemental irrigation on wheat yield and water productivity under different CO_2 and temperature scenarios.

Water harvesting

In dry rangeland environments, up to 90% of rainwater is lost by evaporation, either directly from the soil surface or through runoff

The Vallerani plow, named after its Italian inventor, has mechanized the formerly slow, laborious process of building water-harvesting structures.

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 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 parts of North Africa, ICARDA is integrating simple micro-catchment techniques to rehabilitate degraded rangelands. Forage shrubs are planted around water-harvesting structures. With more water stored in the soil profile, they grow and spread rapidly even in near-drought years, improving vegetation cover, binding the soil to prevent erosion, and providing forage for livestock. Clearly, the technique works. But it's important that local communities are involved, and policies are developed to encourage adoption and ensure sustainability.

Atriplex seedling being planted in a micro-catchment in Jordan. Tens of thousands of Atriplex plants are now thriving; many have survived two consecutive dry seasons.

Food security and climate change

Climate change threatens food security everywhere, but particularly in dry regions already suffering from food shortages. ICARDA's research will continue to address this central issue. Studies on genotypic variation of crops under a combination of high temperature and variable rainfall, under field conditions, will provide new insights. Improved technologies for soil and water management will help conserve and protect natural resources, while ensuring food security for the poor, despite the effects of climate change.

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A Primer on Global Warming

Ajay Varadachary

Temperatures are rising, and are expected to keep rising for centuries to come. What causes global warming, and why should we be worried?

The global average air temperature near the earth's surface rose by 0.74 ± 0.18°C during the last hundred years. The Intergovernmental Panel on Climate Change (IPCC) concludes that most of the increase since the mid 20th century was very likely man-made, the chief cause being burning of fossil fuels. The IPCC also predicts that average temperatures will probably rise a further 1.1 to 6.4°C during the 21st century – different climate models, and different scenarios regarding future emissions of greenhouse gases (GHGs), lead to this wide range of values. A rise of 1°C would be difficult but perhaps manageable; 6.4°C would be catastrophic.

What will the effects be?

Precisely how much warming will occur in a given region is still a matter of conjecture. And whether governments will do what they need to, given the huge economic, social and political costs of reducing GHG emissions, remains to be seen. But there is general agreement on the basic science and the expected impacts.

As temperatures increase, sea levels will rise, drowning low-lying areas – models predict a rise of 18 to 59 cm by year 2100; several hundred million people in coastal areas and small islands could be threatened. The frequency and severity of extreme weather events (rainstorms, cyclones, floods, droughts, very high tides) will increase. Rainfall patterns will change. Some areas at high latitudes might see better rainfall, bigger harvests and less severe cold waves in winter, but food security in many developing countries could be undermined. Disease vectors (for malaria, dengue fever and others) will spread to new areas that become sufficiently warm for the pathogens to reproduce or spread.

Glaciers will retreat, affecting water supplies in high-altitude areas. Many species of plants and animals, unable to adapt to the rapid pace of warming, will become extinct. Higher ocean temperatures will reduce the oceans' ability to sequester carbon. Warmer and more acidic water (dissolved CO_2 forms carbonic acid) will also alter the species composition of marine flora, with profound consequences all along the marine food chain.

What causes climate change?

There are several factors that together cause global warming or cooling. One is variation in the amount of incoming solar radiation, mainly due to variations in the earth's orbit (these variations caused extended periods of global cooling, resulting in the various Ice Ages). Another is volcanic eruptions, which spew large amounts of gases and dust into the air. The gases contribute to warming because they include GHGs, while the dust particles contribute to cooling by reflecting incoming solar radiation back into space. The third factor – and the most important in recent decades – is warming caused by higher concentrations of GHGs in the atmosphere.

Many factors are involved, and most of them interact with each other in fiendishly complex ways, sometimes moderating and sometimes reinforcing the warming effect. For example, the burning of fossil fuels releases CO_2 as well as other pollutants. The warming effect of higher CO_2 is partly offset by some of these pollutants, notably sulfate aerosols, which exert a cooling effect by reflecting incoming sunlight. Clouds contribute to both warming and cooling. The underside of a cloud radiates heat back to the earth's surface, causing warming; while the upper side reflects sunlight, causing cooling.

The scariest bit is 'positive feedback cycles', where warming causes changes that reinforce the warming effect. For example, CO_2 levels rise, temperatures rise, more water evaporates from lakes and oceans… and water vapor (the main GHG) causes still more warming. Or… the polar ice caps melt faster, uncovering land or open water, which reflect less (absorb more) solar radiation than ice does, creating a cycle of warming, melting and more warming.

In theory, positive feedback cycles could lead to a tipping point, beyond which there is no reversal, but a continued, self-reinforcing rise in temperature. There has been considerable discussion about potential tipping points, but no scientific consensus about whether we are anywhere close to a tipping point, or even whether any of the known positive feedback cycles are strong enough to cause tipping.

Whodunit?

We now know that human activity is a major reason for the rising concentration of GHGs. Burning of fossil fuels and deforestation increases CO_2 levels. Farting cattle, emissions from rice paddies, conversion of wetlands to farms or buildings, and industrial fermentation plants, all increase methane levels in the atmosphere. Some agricultural activities, especially the use of fertilizers, increase nitrous oxide concentrations. Industry (refrigeration, fire-fighting systems, some manufacturing processes) produces CFCs, halons and other 'greenhouse molecules'.

What is the greenhouse effect?

In relation to climate change, the term 'greenhouse effect' is a misnomer, because a real greenhouse works differently. A plant greenhouse works mainly by reducing convection losses, while the atmospheric greenhouse works mainly by reducing radiation losses. But work it does – and we should be thankful. Without the greenhouse effect, the earth would be uninhabitable. The average global surface temperature, instead of today's 15°C, would be –19°C.

ADEN AW-HASSAN

Population growth, urbanization, and furious demand for fossil fuels. What chance for Planet Earth?

The atmospheric greenhouse effect has been known for almost 200 years. It was postulated in 1824. By the early 20th century, experiments on various gases had established that several 'greenhouse gases', including CO_2, helped keep the earth and its atmosphere warmer than it would otherwise have been.

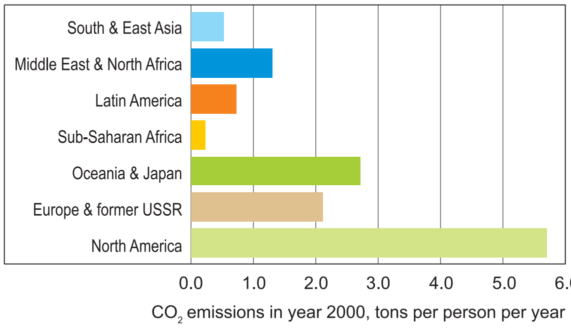
Here's how it works. The earth receives solar radiation in a mixture of different wavelengths. Some of this radiation is absorbed, but about 30% is reflected. Some of the reflected radiation is absorbed by the atmosphere. The rest escapes into the upper layers of the atmosphere and thence into space.

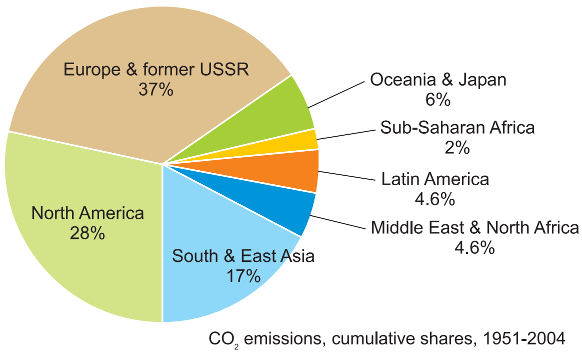
The atmosphere – specifically, gas molecules in the air – thus receives energy from various sources: directly from the sun, from the earth's surface (reflected solar radiation), and from land and water through other forms of heat transfer. In turn, the atmosphere absorbs some of this energy, becoming warmer; and emits some – either down onto the surface, or up into space. Gas molecules absorb and emit mainly infrared radiation, not the shorter wavelengths. The 'greenhouse effect' refers to the process by which infrared radiation emitted by the atmosphere back to the earth's surface causes it to become warmer.

What are greenhouse gases?

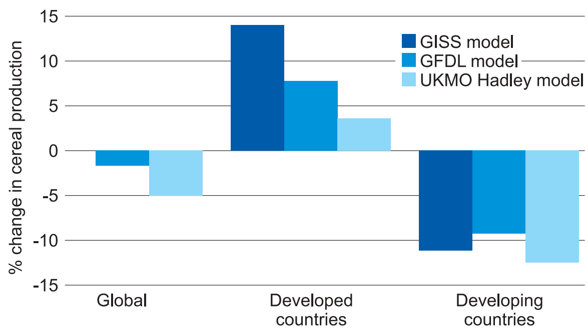
Greenhouse gases, simply put, are gases that cause a greenhouse effect. GHGs occur naturally, although some are produced largely due to human activity. The most important GHG is water vapor, which is responsible for anywhere from one-third to three-quarters of the total greenhouse effect. Others include CO_2, which causes 9-26%, methane (4-9%), ozone (3-7%), and nitrous oxide. Scientists specify a range of possible values because the effects of the different GHGs are not additive. Two plus two could equal three or five (depending on many different factors), but usually not four.

How much a particular GHG contributes to global warming depends on its chemical properties and its relative abundance. Methane is a highly potent GHG, but occurs at low concentrations. Water vapor is much more innocuous, but also far more abundant. The issue is not which gas is responsible, but which gas is increasing, and whether human activity is responsible. The atmospheric concentrations of CO_2 and methane have increased by 30% and 150% respectively, since

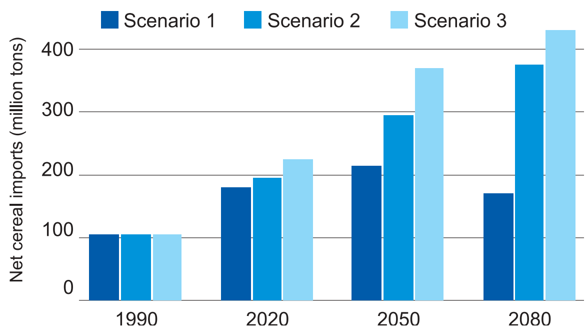




Emissions and equity: developing countries produce far lower emissions per capita, and cumulatively, than the West – but will bear the brunt of the impacts. (Source: FAO)



Effect of climate change on cereal production, projected by three models. All models assume a doubling of CO_2 levels, roughly equivalent to a temperature rise of 3°C. (Source: Stern Report, Govt. of UK)



Net cereal imports by developing countries under three possible scenarios. (Source: IPCC 4th Assessment Report, 2007)

Scenario 1: rapid technological change, more 'clean' technologies. CO_2 concentrations initially increase rapidly but level off, reaching 550 ppm by 2100.

Scenario 2: less rapid technological change, fewer clean technologies.

Scenario 3: few limits on emissions. CO_2 concentrations reach 850 ppm by 2100.

The search for a supermodel

The models used for climate projections are similar in structure to (and often share computer code with) numerical models that predict next week's weather. But climate models are, of course, much more complex.

Weather and climate models are known as General Circulation Models (GCMs). They require enormous computing power, because a range of equations (fluid dynamics, radiative transfer, chemistry, biology) must be solved and integrated forward in time. Simplifications are often necessary, because of limitations in computer power and the complexity of the climate system.

Two kinds of model – atmospheric and oceanic – are coupled together. Add other components, such as a sea ice model or a model for evapotranspiration, and you get a full climate model that can help study climate change processes under different scenarios over different time scales, from a decade to a century. Such models, still under development, will be able to provide detailed regional predictions for the future. Much simpler models (which are themselves extremely complex) are available, and can be used to study specific components of the global system, but cannot provide climate projections.

Typical global climate models use a 100-200 km scale, compared to 40 km (sometimes even 10 km) for weather prediction models.

Consider one subcomponent of an Atmospheric GCM, that focuses on a moving airmass. The model must analyze the fluid dynamics, which depends on factors like surface pressure, velocity in different layers, and temperature and water vapor content in each layer. It must compute the amount of radiation exchanged between the airmass, the earth, and upper atmosphere layers; and factor in the effects of convection, land surface processes and cloud cover. Similarly, a typical Oceanic GCM looks at 'cells' of water measuring 1 degree latitude by 1 degree longitude, split into 20 layers to represent the pressure and temperature gradient – and involves over 1.5 million variables.

How accurate are the models? Given the complexity of the processes involved, it's not surprising that even the best models have several short-comings. For example, there are problems modeling the effect of albedo changes, changes in tropospheric temperature, and most important, the effect of clouds. Despite these problems, several models can reproduce the general features of the observed global temperature over the past century, with a good match between simulated and measured values for many key parameters.

the beginning of the Industrial Revolution. Today's levels are considerably higher than at any time during the last 650,000 years – perhaps even the last 20 million, according to some studies. Current atmospheric CO_2 levels are about 385 parts per million by volume. IPCC models predict they could reach 541 ppm (970 ppm in the worst case scenario) by the year 2100.

Why this increase? By far the most important factor is burning of fossil fuels. Another is deforestation. Unless there is a dramatic change in human lifestyles – or unless we suddenly run out of oil and coal – both factors will continue to play a role in the foreseeable future.

How do GHGs work?

How a molecule responds to infrared radiation depends on its chemical structure and the laws of quantum mechanics. Some molecules (including oxygen, nitrogen and argon, which together form over 99% of the atmosphere) neither absorb nor emit infrared radiation. Others absorb and/or emit, depending on various factors. To make things more interesting, different molecules of the same gas could be in different vibrational states, and therefore behave differently. But in simple terms, some molecules like CO_2, methane and ozone are particularly good absorbers and emitters, and therefore play a major role.

When will global warming stop?

Most studies look at trends up to 2100. But warming and sea level rise are expected to continue for more than a thousand years after GHG levels are stabilized. This is because climate processes and feedback cycles operate over very long time-scales – and particularly because the oceans absorb and release heat very slowly. It took mankind two centuries to create this problem. It could take even longer to solve it.

Ajay Varadachary is a science writer and editor at ICARDA. He has worked in India, Syria and several African countries, writing on agriculture, wildlife, the environment and other issues.

Does Irrigation of Arid Lands Contribute to Climate Change?

Clemens Scheer, Reiner Wassmann, John Lamers and Christopher Martius

Laughing gas is no laughing matter. Results from a pioneering study to measure GHG emissions in the Aral Sea basin in Uzbekistan.

How has global food production managed to keep pace with population growth? One key factor is irrigation. Worldwide, irrigated land has increased nearly six-fold in the past 100 years, from 50 million hectares in 1900 to 277 million hectares in 2003. This increase has made a huge difference to food security, but the impacts of irrigation are far wider, and not always positive.

Irrigation affects virtually all biogeochemical cycles at the field and landscape levels. The most extreme case of irrigation is extended flooding of rice fields, which leads to emission of methane (CH_4), which has a 'global warming potential' 25 times higher than carbon dioxide. But even when fields are not fully flooded (irrigated cotton fields, for example) the irrigation water not only affects the hydrological cycle, but also accelerates the microbial turnover of carbon and nitrogen in the soil. Typically, these irrigated fields stay wet for long periods, and are treated with large amounts of nitrogen fertilizer. Under these conditions, soil bacteria convert the nitrate contained in the fertilizer into nitrous oxide (N_2O) and nitric oxide (NO), which then leak into the air. You're not likely to see them bubble up from the soil, but N_2O is a very effective greenhouse gas – about 300 times as potent as carbon dioxide – and even small quantities, over time and across huge areas, can contribute significantly to global warming.

Theory is fine, but until recently, there was very little quantitative data on irrigation-related greenhouse gas (GHG) emissions in arid regions, especially in the developing world. In 2005, the Center for Development Research (ZEF) of the University of Bonn, Germany,

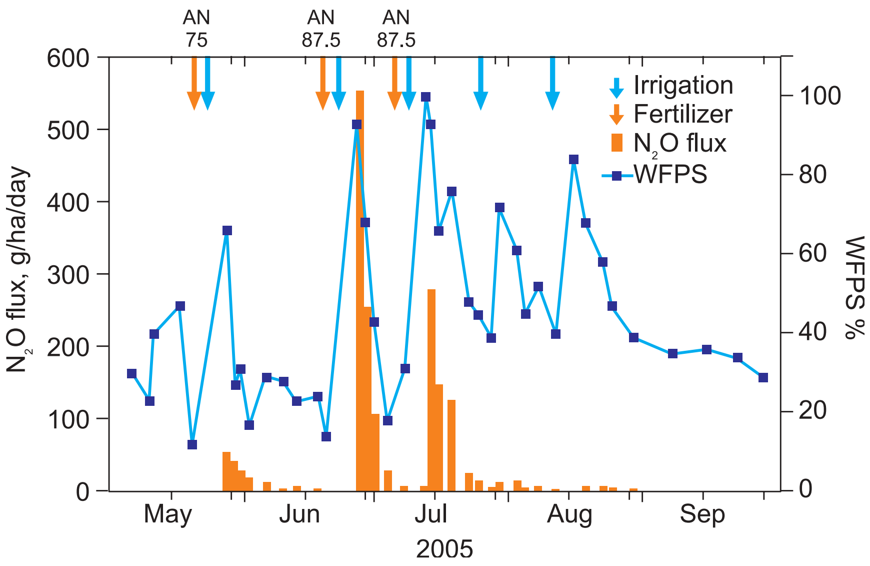


Figure 1. N_2O flux rates and WFPS (water-filled pore space, a measure of soil water content) in cotton fields, May to September 2005. The fertilizer was Ammonium Nitrate, applied at 75 or 87.5 kg N per hectare.

began a 2-year study in the Aral Sea basin, funded by the German Ministry for Education and Research. The study focused on the irrigated areas of the Khorezm region in western Uzbekistan, where conditions (climate, cropping patterns, land use) are representative of vast areas across Central Asia and the Caucasus. The aim was to examine how the main land-use systems in the region contribute to N_2O and CH_4 emissions, and identify management and irrigation practices that could reduce these emissions without reducing food output.

Irrigated farming in the Aral Sea basin turned out to be a significant source of GHGs. It produced high emissions of N_2O from cotton and wheat fields, and even higher emissions of CH_4 from flooded rice fields. Soil N_2O flux (the level of N_2O emissions produced by the soil) varied during the cropping season, depending on fertilizer and irrigation management. But 80-95% of the total N_2O flux in cotton and wheat occurred in short bursts or 'pulses', immediately after a field received fertilizer + irrigation in combination (Fig. 1).

The study also assessed GHG emissions from perennial land-use systems. Measurements were conducted in a plantation of poplar trees and in the natural Tugai riparian forests along the Amu Darya river. The natural Tugai forests produced only negligible fluxes of N_2O and CH_4. The unfertilized poplar plantation emitted about 15 times as much GHGs per hectare (mainly in the form of N_2O) as the natural forests.

GHG emissions depend critically on how the land is being used – forest, tree plantations, wheat fields, cotton fields, etc. The study measured emissions in each of the major land-use systems in the region (Fig. 2). The Tugai forest had the lowest GHG emission rates: 200 grams of CO_2 equivalents per hectare per day. Irrigated rice fields had the highest, 10.1 kg of CO_2 equivalents per hectare per day.

There were large differences between crops. Rice, the worst offender, produced mainly methane. Cotton was next-to-worst, with a damage potential similar to rice, producing mainly

Rice fields produced the highest emissions. Constant flooding cuts off the soil's oxygen supply, resulting in high methane emissions from heavily fertilized fields.

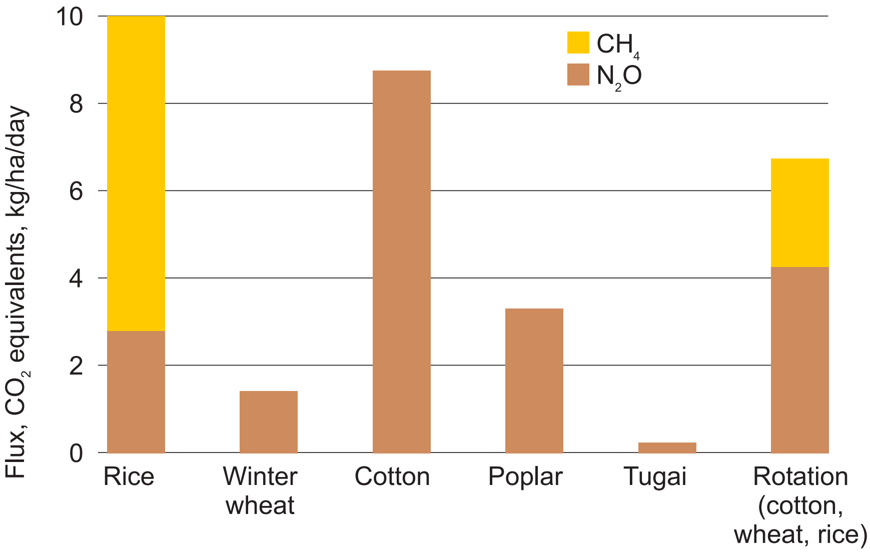


Figure 2. Mean daily flux rates of N_2O and CH_4 (measured in CO_2 equivalents) in different land-use systems.

N_2O. Wheat also produced mainly N_2O, but at much lower levels than cotton, partly because wheat in Uzbekistan is grown in winter, when temperatures, and therefore soil microbial activity, are low.

Many farmers in this region practice a two-year rotation of cotton-wheat-rice. This system produces an average of 2.5 tons of CO_2 equivalents per hectare per year. If all the irrigated farmland in Uzbekistan (4.3 million ha) had the same emission rates, it would produce N_2O and CH_4 fluxes totalling 10.5 million tons of CO_2 equivalents per year, i.e. about 7% of the country's total man-made emissions.

What are the implications of these figures? On one hand, soil fluxes of N_2O and CH_4 from irrigated farmland contribute only a small portion of Uzbekistan's total GHG emissions. On the other hand, any reduction in GHGs would be welcome; and reducing irrigation-related emissions would tie in perfectly with policies for sustainable development, by improving environmental quality, and making better use of scarce water resources. What should make farmers and policy-makers think is that up to 70% of the precious – and expensive – nitrogen fertilizer ends up not in the plant but in the air! Lower GHG emissions would increase fertilizer-use efficiency and reduce farming costs. Therefore, any policies to improve land management in irrigated areas in Central Asia should include mitigation of soil GHG fluxes.

Can such mitigation efforts succeed? Scientists are optimistic, for two reasons. First, different land-use systems produce very different N_2O and CH_4 fluxes – so emissions could be cut by promoting low-flux systems. Second, improved fertilizer and irrigation practices would not only cut emissions but also appeal immediately to poor farmers as the nitrogen fertilizer would be used more efficiently. Clearly, there is considerable scope for reducing GHG emissions by making simple changes in the current farming system. But farmers will make these changes only if they offer additional benefits such as higher yields or lower production costs – they are unlikely to implement alternatives that benefit the environment alone.

Given these realities, what practical steps should we take? We could begin with small changes. The bulk of N_2O emissions occurs in bursts (see Fig. 1) when irrigation and fertilizer are applied simultaneously. Therefore fertilizer application in combination with extensive irrigation should be avoided whenever possible. But more research is needed before specific recommendations can be made.

Forests – and especially natural forests rather than wood plantations – produce lower emissions than most other types of land use.

Optimal cropping systems can improve soil fertility and reduce GHG emissions without reducing farmers' profits.

Management practices that increase fertilizer-use efficiency in irrigated systems, such as sub-surface fertilizer application (which requires special machines but could reduce emissions), and drip irrigation (which would reduce duration and extent of soil wetting and improve the water balance) will also reduce N_2O emissions. Choosing appropriate rotations and managing crop residues properly – for example, reducing the need for mineral fertilizer by using crop leftovers for mulching – can also reduce emissions. For rice, varieties with low methane emissions are available and should be promoted.

Another argument for better land management strategies relates to denitrification, the process by which nitrate and nitrite compounds, which plants can absorb, are converted by bacteria into gaseous nitrogen, which plants cannot absorb. This means that a large part of the expensive nitrogen fertilizer is lost. Several solutions are available. Switching some land from annual crops to perennial forest plantations – especially on marginal lands – would reduce land degradation, reduce N_2O and CH_4 fluxes, and most important for the farmer, reduce consumption of fertilizer and fuel, which together make up over 40% of the total production costs.

Forests and tree plantations sequester carbon. Trees breathe in CO_2, the carbon is trapped and accumulates in the soil and the wood. And commercial plantations offer substantial income opportunities. Apart from the sale from wood (used for fuel), there are fruits and leaves (for fodder) to be harvested.

Also, there is an emerging market for carbon trading from the Kyoto Clean Development Mechanism and other certification schemes. If properly tapped and managed, this market could provide the financial incentives that would persuade farmers to switch to more environment-friendly practices.

In summary, a mix of optimal cropping systems including tree plantations would reduce GHG emissions, and simultaneously improve carbon sequestration, increase soil fertility, prevent soil degradation, and increase farm incomes. Effective, low-cost, easy-to-implement technology 'packages' are available. What is needed is stronger policy support to encourage adoption of these technologies.

Does this sound too good to be true? More research is certainly needed, to better understand the effect of different nitrogen-management strategies, tillage methods and residue management practices on carbon and nitrogen fluxes in drylands. Easy-to-follow practices have to be developed. But the data so far are very encouraging and warrant further research. ICARDA's Regional Program for Central Asia and the Caucasus will be involved in some of these studies, as part of a research consortium that includes the German-funded ZEF Landscape Project, national research centers in Uzbekistan, Tajikistan and Kazakhstan, and several CGIAR Centers.

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Trapped!

Carbon Sequestration and Soil Organic Matter

Soil organic matter plays a key role in C sequestration. Long-term experiments look at simple management methods that improve crop yields as well as sequestration.

John Ryan

Three of the world's biggest problems are food security, soil degradation and global warming. All are related, in varying degrees, to human activity. They are also influenced by another common but largely unappreciated factor – soil organic matter. Soils with high levels of organic matter are more productive and more resistant to degradation processes. They can also contribute to reducing climate change, because they contain more carbon (sequestered from the atmosphere) than do soils with low organic matter content.

Plants absorb carbon dioxide from the air, and produce biomass by photosynthesis. Part of this biomass is harvested; part remains sequestered in the soil as organic matter (essentially, various carbon compounds). Even a small improvement in organic matter levels in soil, i.e. more sequestration, means that less carbon (or carbon dioxide) remains in the atmosphere to cause global warming. This article describes a series of long-term experiments conducted at ICARDA, that show how organic matter content can be improved by better management of soil and crops.

SOM soils are healthier

Soil health and crop productivity depend on many factors. One key factor is the relatively small but disproportionately influential component, soil organic matter (SOM), also known as the soil carbon fraction. SOM levels depend on how much organic matter (roots and residues of crops) enters the soil, which in turn depends on crop yields; and how much soil carbon is lost through mineralization – which depends on climatic factors such as temperature and soil moisture.

Despite its importance, SOM research was not always a priority, especially in the Mediterranean region where ICARDA works – and where most soils are low in organic matter. Since the 1970s, research has expanded, for three reasons. First, declining per-capita availability of arable land, and concerns about sustainability, made it essential to improve SOM management. Second, cropping systems changed. Small farms with multiple crops, where nutrients were continuously recycled within the system, gave way to large farms specializing in one or two crops, relying on external nutrients (lots of fertilizer) rather than nutrient cycling. Third, the role of SOM in carbon sequestration became more widely recognized as a result of global concerns about carbon dioxide and global warming.

Beginning in the early 1980s, several long-term trials at ICARDA sought to assess cropping system sustainability. The initial focus was on crop yields: we examined the role of SOM in providing nutrients and improving aggregation or physical quality of soils. More recently, we began exploring how SOM contributes to carbon sequestration; the connection between SOM and various soil and crop management methods; and the implications for climate change.

Measuring cropping system productivity

The 14-year experiment on cropping systems productivity was ICARDA's 'flagship' cereal-based rotation trial, conducted at the Center's headquarters in Tel Hadya, Syria. Seven crop combinations were tested: continuous durum wheat, and various wheat rotations, i.e. wheat in rotation with fallow, pseudo-fallow (watermelon), and four legume crops (lentil, chickpea, vetch, medic). Lentil and chickpea are important food crops, while vetch and medic are grown for forage.

For each of these seven combinations, we measured SOM levels before, during and after each stage of the cycle. We also measured how SOM levels were affected by two other factors: application of nitrogen fertilizer, and grazing of crop stubble. Nitrogen (N) was applied to the cereal phase in each combination, at four levels ranging from zero to 90 kg per hectare. The stubble was grazed by sheep at three intensity levels, low, medium and high.

Increase in SOM due to rotations, nitrogen application and grazing

Rotations	Fallow 1.07%, Melon 1.07%, Continuous wheat 1.12% Lentil 1.13%, Chickpea 1.17%, Vetch 1.2%, Medic 1.32%
Nitrogen	None 1.12%, 30 kg 1.13%, 60 kg 1.19%, 90 kg 1.20%
Grazing	None 1.20%, Medium 1.15%, High 1.14%

Since biological processes are usually long-term, measurements began only in the 1989/90 season, after allowing several years for the effects to become measurable. We found a gradual overall increase in SOM in every rotation, although the rate of increase was different for different crops (see table). In the last few years of the trial, an apparent equilibrium or plateau level was reached, beyond which no further increases are possible. Despite the absence of initial baseline SOM measurements, there were clear patterns showing the influence of each of the three factors: crop rotation, N fertilizer, and stubble grazing.

The fallow and pseudo-fallow (melon) rotations had the lowest SOM levels. The two forage legumes, medic and vetch, had the highest. These results are for total SOM, which is relatively stable. Levels of the more reactive SOM fractions generally followed the same trends but fluctuated throughout the season.

Why were fallow plots the poorest? Summer fallowing accelerates the loss of organic matter, partly because of temperature and moisture factors, and also because no residues are added to the soil, leading to a net loss of organic matter. In contrast, forage legume rotations gave the highest SOM, because of the inputs of roots and fallen leaves.

Application of N fertilizer produced a small but consistent increase in overall SOM levels: N improves crop yields, so more biomass is available for potential conversion to SOM. Grazing produced the opposite effect, with the lowest SOM increase under heavy grazing.

Sheep and sequestration

In most developing countries, livestock graze on crop stubble left after the harvest. Another long-term experiment at ICARDA (1987-98) focused on how grazing pressure affects SOM levels in different crop rotations. The rotations involved a continuous cereal crop (originally wheat, later barley), cereal-fallow, and cereal in rotation with pasture legumes (medic and vetch). Each rotation was subjected to various levels of grazing pressure.

The results were similar to those from the first trial. Legume rotations had the highest increases in SOM. For example, when no fertilizer was used in the rotation (as often happens in subsistence farming) legume plots had 40% more SOM in the topsoil compared to continuous barley and about 20% more than barley-fallow. Shallow-rooted crops returned less organic matter into the soil. SOM values decreased as grazing intensity increased, because more grazing means more biomass is removed from the field, leaving less to be converted into organic matter. (However, medium grazing pressure can sometimes be beneficial, because the sheep trample plant shoots into the soil.) SOM values were consistently higher where nitrogen fertilizer was applied.

Tillage, compost and residues

The third experiment began in 1996, and is still continuing. It looks at SOM in the context of two key factors: conservation tillage and residue management – which now form part of standard recommendations in many countries. The trial involves a barley-vetch rotation, under different kinds of tillage, different levels of compost application, and different methods of using (or disposing of) straw and crop stubble.

The biggest effect on SOM came from addition of compost (10 tons per hectare, applied every 2 years or every 4 years). Tillage also had a major impact on SOM, particularly in the top 30 cm. Regardless of other factors, shallow tillage, using an implement known as a ducksfoot plow, led to significantly higher SOM than conventional deep tillage with the standard moldboard plow (Fig. 1).

Wheat/fallow plot on left. Wheat/medic on right, with taller, healthier, dark green plants, reflecting the cumulative effect of increased SOM and nitrogen.

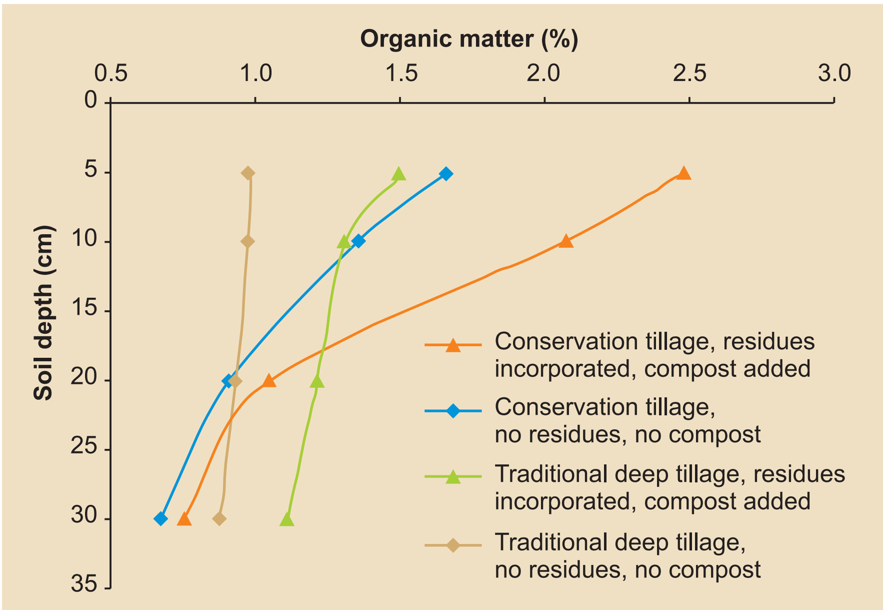

Fig. 1. Organic matter levels under different farming practices. Good practice: add compost, use shallow tillage rather than conventional deep tillage, and incorporate crop residues into the soil. Compost added at 10 tons per hectare, applied every 2 years.

More food, less warming

SOM measurements were also made in several other trials with different parameters (e.g. rainfall differences, phosphorus fertilizer, different crop rotations). The trends were the same. SOM, and therefore carbon sequestration, can be improved through simple management techniques such as legume rotations, shallow or conservation tillage, application of fertilizer or compost, and incorporation of crop residues into the soil.

SOM represents less than one percent of soil by weight, but has a disproportionately large influence on soil health and sustainability of the farming system. Development specialists and policy makers will find one result particularly interesting: modern practices such as intensive forage/cereal rotations, nitrogen fertilization and conservation tillage, which were designed to improve crop productivity, can also help fight global warming by promoting carbon sequestration.

Soil Organic Matter

Soil organic matter (SOM) is formed from the decomposition of plant and animal tissue. This decomposition occurs in several stages, with organic material undergoing a series of chemical changes, often driven by bacterial action. SOM is a mixture of numerous organic compounds, from stable fractions that are resistant to decomposition, to relatively unstable fractions.

But even the stable fraction is not completely stable: about 5% is lost every year through a process known as mineralization, in which SOM is broken down to its components by soil microbes. The rate of mineralization depends on temperature, oxygen availability, and moisture levels in the soil.

While SOM can break down quickly, it builds up very slowly. Less than 10% of organic material that enters the soil eventually becomes stable organic matter. As a rough example, adding 100 tons of organic material (manure, dead leaves, etc) to a one-hectare field will, under favorable conditions, eventually produce 1% stable SOM in the topsoil.

SOM levels depend on soil and vegetation characteristics; 8% would be exceptionally high; desert soils normally have much less than 1%, and ICARDA's research station at Tel Hadya has 1.0 to 1.4%. Soils in grassland areas have fairly high SOM, because organic material is supplied by roots as well as above-ground parts of the plant. When grassland is converted to crop fields, SOM levels decline, because biomass retention is greatly reduced (grass is naturally recycled, while crop plants are harvested and removed), and also because decomposition processes are accelerated by cultivation – especially by heavy tillage.

Rainforest soils usually have low SOM levels, because much of the organic material is tied up in trees and surface litter or rapidly recycled instead of being returned to the soil.

How does SOM help?

- *Nutrient recycling*. SOM is formed from organic matter, and therefore contains a range of nutrients. Equally important, these nutrients are in plant-available form, i.e. the decomposition process converts compounds into other forms that plants can absorb more easily.
- *Water-holding capacity*. SOM can hold up to 90% of its weight in water. This water is then released gradually, ensuring that soil moisture levels remain high for longer periods.
- *Soil structure*. SOM causes soil particles to clump together. This improves soil structure, and therefore water infiltration.
- *Erosion control*. Better soil structure and water infiltration helps control erosion. Increasing SOM from 1% to 3% can reduce erosion by 20% (even 30% under some conditions).

These benefits will become increasingly important with climate change. For example, climate models predict more severe droughts (often associated with erosion), as well as more severe rainstorms (when high infiltration rates are important).

How to increase SOM?

- Reduce or eliminate tillage. Conventional tillage creates excessive aeration of the soil leading to a flush of microbial action that speeds up the decomposition of organic matter.
- Reduce erosion. Most SOM is in the topsoil. When soil is lost, so is organic matter. Various practices, e.g. cover crops, can control erosion.
- Add fertilizer or manure. This increases biomass production. Even if above-ground biomass is removed at harvest, the increased root growth will help increase SOM.

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Carbon Sequestration

in the Soils of Central Asia

Studies on carbon sequestration in Central Asia lead to some surprising conclusions.

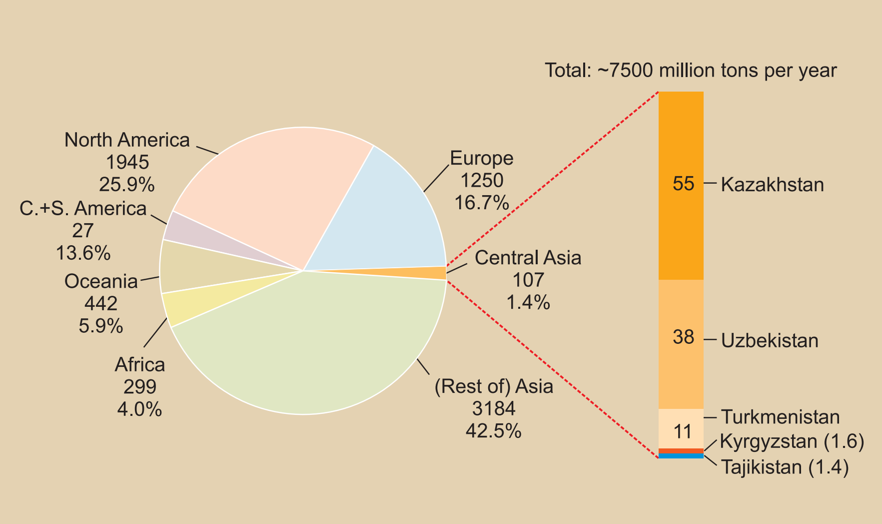

CHRISTOPHER MARTIUS

Rolf Sommer and Eddy de Pauw

Carbon sequestration is a term you often hear in the climate chage debate. Carbon enters the atmosphere as carbon dioxide when fossil fuels are burnt. In theory, a significant proportion of this carbon could be sequestered by soils, i.e. captured and stored as organic matter or carbonate minerals, taking it out of the global warming equation. In practice, there are doubts about whether the gains would be meaningful in the context of global CO_2 emissions. Recent research in Central Asia, where soils and agro-ecosystems are believed to have considerable potential for carbon sequestration, puts these issues in perspective.

The five countries of Central Asia – Kazakhstan, Kyrgyzstan, Uzbekistan, Tajikistan and Turkmenistan – cover nearly 4 million square kilometers. A large proportion of this area is steppe, used mainly to graze sheep. Could these areas potentially serve as carbon sinks, sequestering carbon for the world's benefit and generating income for the country through international carbon-trading agreements?

Central Asia, with about 3% of the world's land (excluding Antarctica), accounts for only around 1.4% of the CO_2 that is set free worldwide by fossil fuel burning. About half of this comes from Kazakhstan, which occupies about two-thirds of Central Asia. One-third comes from Uzbekistan, which has the region's highest population. The other three countries are smaller and less populated.



Global CO_2 emissions (million tons carbon per year) from burning of fossil fuels. Data are for 2004. Source: Carbon Dioxide Information Analysis Center. Central and South America includes the Caribbean countries. Oceania comprises Japan, Australia and New Zealand (together, 99.6% of Oceania's total) and twelve other states in the Pacific Ocean.

Sources and sinks

Where is carbon found? Pretty much everywhere: underground coal deposits, dissolved compounds in sea water, animals, plant tissue. The world's oceans are by far the largest carbon pool, containing nearly 40 trillion tons. Soils are the next largest, containing about three times the amount of carbon bound in living plants and animals. In terms of climate change, buried or 'bound' carbon does no harm – but carbon in the atmosphere (mainly as CO_2) is a major factor in global warming.

Human activity is reducing the effectiveness of soils as carbon sinks. Conversion of natural grasslands and forests into agriculture causes heavy losses of soil organic carbon, partly because inappropriate practices such as heavy tillage expose buried organic matter to air and sunlight, accelerating the release of carbon. The biggest culprit is deforestation, which often involves clear-burning of large swathes of forest. By some estimates, all these changes in land use have released 156 billion tons of carbon into the atmosphere over the past 150 years. The rate of emissions (currently 2 billion tons per year) is increasing.

That is just from changes in land use. Burning of fossil fuels (coal, gas, oil) is far more serious, releasing 7.5 billion tons of carbon per year.

Carbon pools

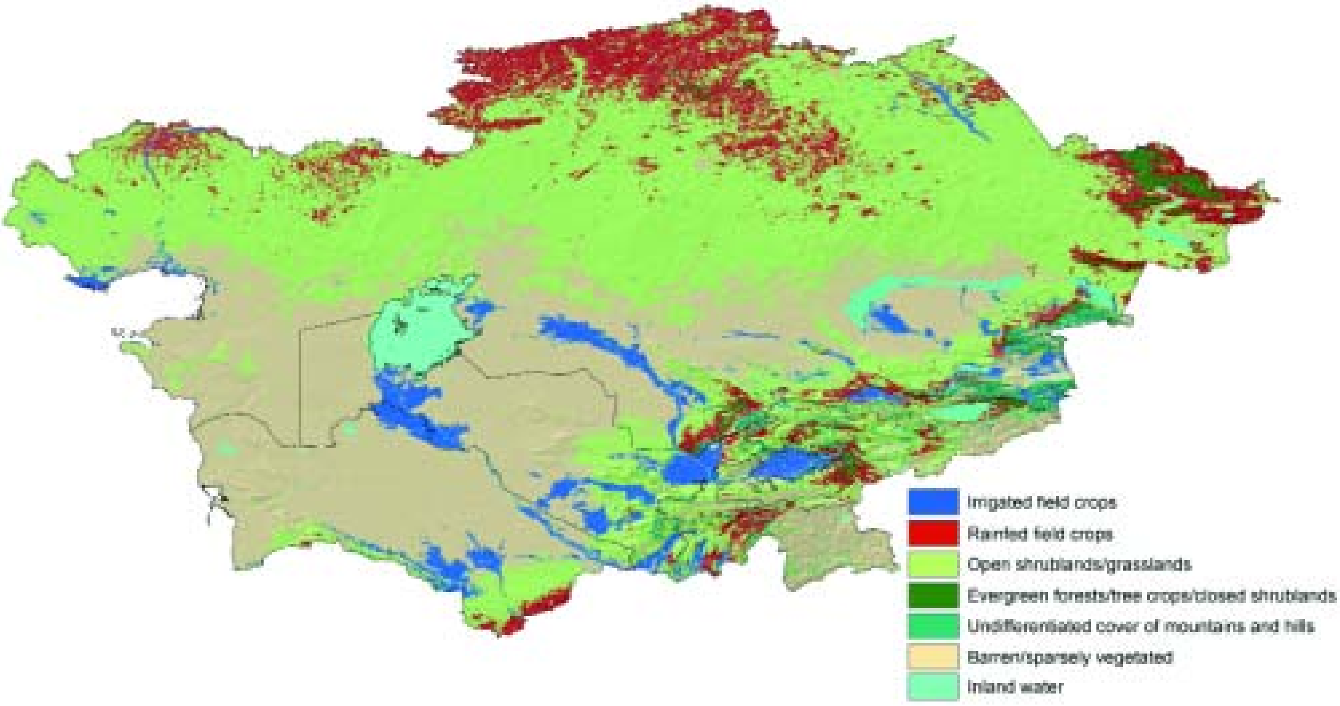
	Carbon, billion tons
Ocean	38 - 39000
Atmosphere	785
Animals, plant tissue	466-835
Geologic (coal, gas, oil)	4000-5000
Soil organic carbon	1220-1550
Soil inorganic carbon	750-950
Soil, total (1 meter depth)	2000-2500

How land use affects carbon stocks

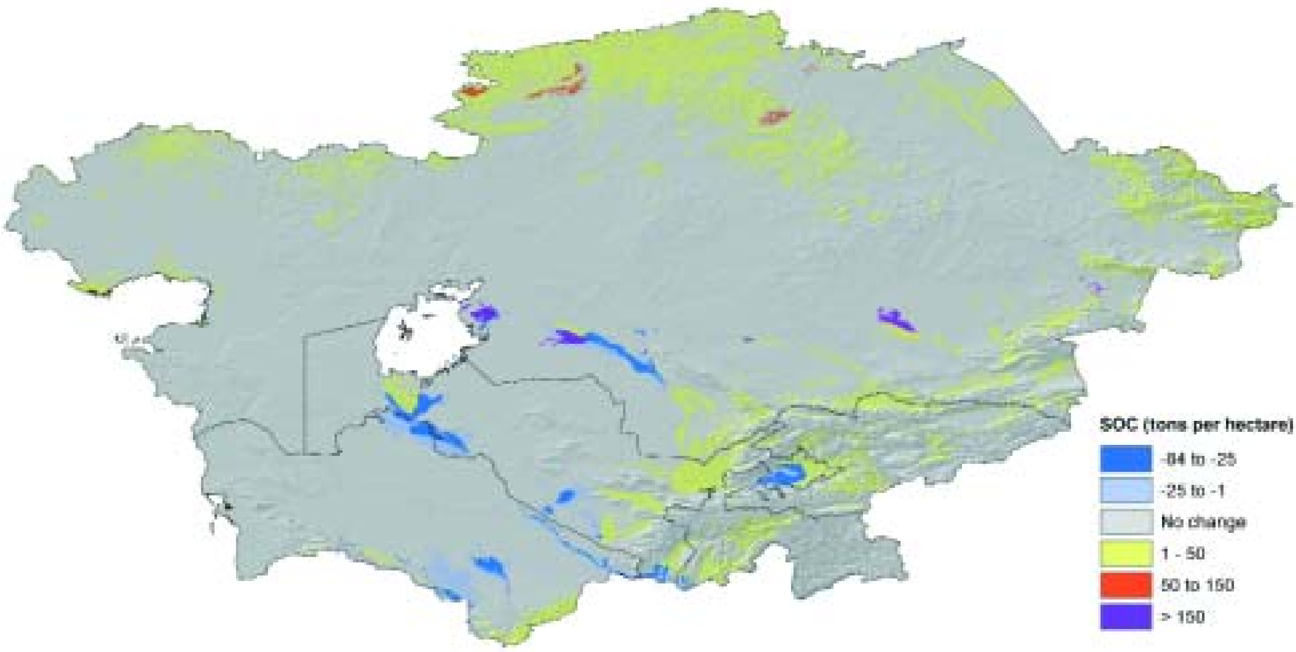
The steppes of northern Kazakhstan cover 126 million hectares, or 43% of the country's area. The amount of carbon in steppe soils depends heavily on climate as well as land use. Soils in warmer, drier, and lower-latitude areas contain less carbon. Conversion from virgin land to cultivation led to losses of 9% to 21% in soil carbon levels, with one caveat. Especially in arid areas, conversion to irrigated (as opposed to rainfed) farming actually increases organic matter, because irrigated farmland produces more biomass, and therefore potentially more soil carbon, than virgin land.

To better understand the influence of land use on soil carbon stocks, ICARDA scientists used GIS analysis. Data from various studies were compiled, standardized, and overlaid onto soil and land-use maps. Consider the two maps on page 35. Map 1 shows land-use categories in Central Asia: open grasslands in the north, barren or sparsely vegetated land in the south, rainfed agriculture in some areas, especially in northern Kazakhstan, and a few patches where high-yielding irrigated crops are grown. Map 2 shows how crop production reduces the amount of soil organic carbon (SOC).

The red areas in Map 1 are 'hotspots' of high SOC depletion. These include, for instance, wetlands with SOC-rich soils, which were drained for cultivation. On the other hand, SOC has increased in some areas along the Amu Darya and Syr Darya rivers (blue), where desert areas were converted to intensive irrigated agriculture.



Map 1. Land use categories in Central Asia



Map 2. Losses of soil organic carbon in Central Asia due to crop production

Most of Central Asia still remains uncultivated. But the limited conversion to farmland has already reduced overall SOC levels in Central Asia by 3 to 4%, releasing over 780 million tons of carbon into the atmosphere. Degradation of rangeland due to overgrazing has caused further losses, but these are hard to estimate. ICARDA and partner institutions in the region are discussing research plans to examine the scale and level of rangeland degradation, and the impact on SOC stocks.

The Kyoto Protocol

The Kyoto Protocol is an international agreement (under the UN Framework Convention on Climate Change) on reducing 'greenhouse gases'. It was agreed in Kyoto, Japan, in December 1997 and came into force in February 2005. So far, over 175 countries (including 137 developing countries) have ratified the protocol. Notable exceptions include the USA, the world's biggest emitter of CO_2, which has signed but not ratified it. Kyoto expires in 2012, and talks on a future treaty began last year.

Countries that ratify the protocol commit to reducing their emissions of six greenhouse gases (CO_2, methane, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons and perfluorocarbons), or engaging in emissions trading if they fail to reduce emissions. Developed countries must reduce emissions to specified levels, with penalties for non-compliance. Developing countries will simply monitor and report emissions, without specific reduction targets. But there are various riders and caveats.

By 2012, developed countries have to reduce their GHG emissions by a collective average of 5% below 1990 levels, although targets are different for each country. For many countries, the 2012 targets are 15% below 2008 levels, while some countries can actually increase their emissions without falling afoul of Kyoto. Countries can meet their targets either by reducing emissions or by purchasing 'carbon credits' from other countries – this may sometimes be cheaper than modifying factories or power plants, and aims to allay fears that over-zealous reductions will affect economic growth.

Developing countries have no reduction targets, but can still sell carbon credits, which they can acquire by setting up 'clean energy' or emissions-reduction projects. The carbon credits are issued by the Clean Development Mechanism, an international body set up to evaluate and approve 'clean energy' projects and regulate the international trade in carbon credits. This gives developing countries a financial incentive to actively contribute to reductions, even though they have no mandated targets.

The benefits of sequestration

Organic matter levels, and therefore capacity for carbon sequestration, have declined in large parts of Central Asia. Solutions are available – different crop rotations, better management practices (in particular, reduced tillage), improved grazing management – that can increase SOC back to its original levels, or even higher.

But implementing these solutions will be hard, for two reasons, First, the potential for improvement is variable, being dependent on local conditions such as soil type, availability of irrigation etc. Second, and more important, it will be difficult to promote these solutions widely in a region where rural communities are poor and widely scattered, and government infrastructure is lacking.

But let's take an optimistic view. Assume that SOC levels in all of Central Asia's cropland can be restored to native levels in the next 50 years. This means 15.7 million tons of carbon can be sequestered each year. Will this make a dent in atmospheric CO_2 levels? This 15.7 million tons represents nearly 15% of Central Asia's annual anthropogenic carbon emissions, but only 0.2% of global emissions. One view is, of course, that every bit helps. But more importantly, sequestration would represent a huge income opportunity in a region with high poverty and severe under-investment.

The Clean Development Mechanism (CDM) under the Kyoto Protocol (see box) offers opportunities for countries to sell carbon sinks on the international carbon market. Sequestering 15.7 million tons of carbon per year, at the current price of €25.75 per ton, will be worth approximately 403 million Euro. And this does not include the potential for carbon sequestration in currently degraded rangelands.

However, soil carbon sequestration is currently not eligible for CDM funding, for both policy and technical reasons (e.g. difficulties in measurement and monitoring). Steppe areas play an important role in the carbon cycle, but not so far in the carbon-credit market. If these issues can be resolved and soil carbon included in CDM or similar schemes, the benefits could be substantial.

The economies of Central Asia are heavily dependent on agriculture. Higher SOC levels would improve soil fertility, food production, ecosystem sustainability, and livelihoods of the rural poor, who form the majority of the population. Soil carbon sequestration would be a positive side-effect: not so much in terms of reducing climate change, but as a significant source of income for national governments.

The authors are with ICARDA, based in Aleppo, Syria. Rolf Sommer (r.sommer@cgiar.org), formerly with the University of Bonn, is a soil scientist and modeling specialist, and has worked in Brazil, Mexico and Uzbekistan. Eddy de Pauw (e.de-pauw@cgiar.org) is a climatologist and remote sensing specialist, and head of ICARDA's GIS Unit.

Livestock and Climate Change:

Local Breeds, Adaptation and Ecosystem Resilience

Markos Tibbo, Luis Iñiguez and Barbara Rischkowsky

Heat-resistant sheep? Hardy local breeds can help cushion livestock producers against climate change.

In the discussions about climate change, one aspect is sometimes forgotten: the impacts on small-ruminant production. Small ruminants (sheep and goats) are a key part of the rural economy. In many dry areas, they are the most important sources of food and income; and anywhere from 60 to 90% of the land, being unsuitable for crop farming, is used to graze livestock.

Climate change will impact on producers and their flocks in various ways: heat-stressed animals, scarcity of water and fodder, changes in the dynamics of disease epidemics. Climate change will likely cause significant losses of livestock numbers, and even loss of breeds with small populations or restricted distribution. As conditions change, it becomes ever more important to have breeds that can cope with change.

Sheep and goats were first domesticated at least 8500 years ago. The most important center of domestication was the Fertile Crescent, covering parts of modern-day Iraq, Syria and Iran. Correspondingly, the region has a very wide diversity of animal breeds. ICARDA and its partners are helping to document this diversity, identify breeds (and specific populations) at risk, and help countries use this unique genepool more effectively. For example, this research will help identify adaptive traits that enable animals to thrive even when conditions become harsher. It will also help tailor husbandry practices to breed requirements, and to changed climatic conditions.

Indigenous solutions

The WANA region (West Asia and North Africa) has 75 local breeds of sheep and at least 32 breeds of goats. Some thrive in deserts; others are adapted to oases or humid coastal regions, others to steppe areas. Most of these breeds are tolerant to temperature extremes and can remain productive even on degraded rangeland.

Some breeds are widespread (e.g. Awassi sheep, which are found in at least six countries in the region), or becoming more so as a result of demand. Shami/Damascus goats from Syria, for example, are highly sought after by breeders in North Africa. But many local breeds are at risk, for a variety of reasons.

The biggest factor is markets. Turkey's Angora goat population has collapsed because of difficulties in marketing mohair; production in Central Asia has severely declined because the old market systems no longer work. Another threat is indiscriminate crossbreeding. Seeking to increase productivity, farmers cross their local breeds either with non-adapted 'exotic' breeds or with other local breeds found nearby. Fortunately, despite this decline in genetic diversity, only a few of WANA's local breeds are at serious threat of extinction.

Sheep. Over 70% of the sheep breeds in WANA are fat-tailed, an adaptation that allows them to cope with fluctuations in feed availability. They deposit fat in the tail during periods of feed abundance, and mobilize the fat deposits during periods of scarcity. Some fat-tailed breeds are becoming inbred, for example the Chal, Moghani, Sanjabi and Zel in Iran. Others are in even greater danger. In Turkey, only a few Güneykaraman and Gökçeada sheep remain; and the Ödemis is close to extinction.

Goats. There have been few studies on the status of indigenous goat breeds. But we do know that many are under threat because of indiscriminate crossbreeding (e.g. Jabali or mountain goats in Lebanon, Zaraibi goats in Egypt) or small population size (Dihewi, Norduz, Gürcü, Abaza). Goat meat and milk, in general, are less popular than sheep products; and goat farmers lack the institutional support (e.g. cooperatives) to compensate for this disadvantage.

A milestone in Morocco

Morocco is the only country in the WANA region with a comprehensive, science-based policy to protect local breeds. Areas are classified as breeding, crossbreeding, or traditional breeding zones. In the 'breeding zones', farmers are permitted to rear only indigenous breeds, or breeds long established in the area. In the 'crossbreeding zones', terminal breeding is permitted (two breeds are crossed, and the offspring are slaughtered before they reproduce). In the 'traditional zones', where populations and diversity are fairly high, there are no restrictions. The policy was introduced in the late 1990s. Studies on its impact will help develop similar plans for other countries in the region.

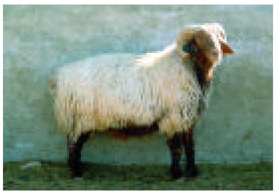
Another problem is that there are no clear estimates of the value of local breeds and production systems. This has encouraged crossbreeding; either promoted by local governments or by farmers themselves. In this process, farmers who crossbreed their animals with non-adapted European breeds have tended to suffer more than those who cross with breeds adapted to dry areas (e.g. the Shami goat).

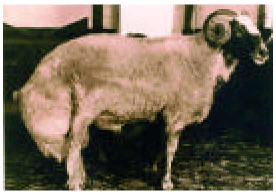
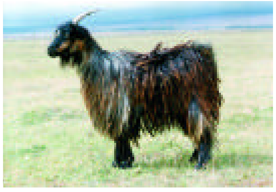
Why local breeds?

Local breeds are likely to cope better with climate change than exotic breeds, because they are already adapted to drastic changes – temperature extremes or periods of acute feed scarcity. Breeding programs will not be able to improve adaptation traits in exotic 'improved' breeds fast enough to keep pace with climate change. The better alternative is to focus on improving specific traits (e.g. fertility, milk yield, growth rate) in local breeds.

But this presents serious challenges for animal breeders. Local breeds are owned mostly by small-scale farmers or nomadic pastoralists – which usually means small flocks, lack of animal identification, and absence of written records. ICARDA and its partners are using a new approach – community based participatory breeding – to overcome these challenges. Participatory breeding projects have been implemented in Ethiopia, Mexico, Kyrgyzstan and Tajikistan, in partnership with national research centers, the University of Natural Resources and Applied Life Sciences (BOKU) and the International Livestock Research Institute.

First, the community identifies specific breeding objectives. The entire community flock is then used as a single 'breeding pool' to improve the target traits. Together with genetic improvement, these projects also promote improved husbandry methods and market linkages.

New science

Many indigenous breeds have not been fully studied. What adaptive traits enable them to survive under arid conditions? What characteristics are important under changing market conditions? What are the genetic relationships between and within breeds? Studies by ICARDA and its partners are helping to fill these information gaps.

The first study, in collaboration with BOKU, examined goat populations in Syria, using phenotypic as well as molecular genetic characterization. A field survey of goat production systems was followed by phenotypic characterization through photographs and body measurements, blood sampling for DNA analysis, and genetic characterization using microsatellite DNA markers. The results have provided a better understanding of traits and genetic diversity in different agro-ecological zones, and the implications for breed utilization and conservation. They have also helped understand the impact of specific policies: for example, grazing restrictions in forest areas are an important limiting factor for Jabali goat production systems.

Butchers and biodiversity

Economic factors can sometimes be critical: breeds with limited market value could quickly disappear, especially if their geographical distribution was limited to begin with. In Tunisia, for example, producers of fat-tailed Barbarin sheep have been systematically crossing their Barbarins with thin-tailed sheep, for several years. A study by ICARDA and the Tunisian national research program discovered that the change was driven not by consumers or producers, but by butchers.

The problem was the fat tail. This adaptation enables the Barbarin (and other fat-tailed breeds) to survive long periods of feed scarcity. But butchers found it hard to sell the tail, which accounts for 15% of the carcass weight. Consumer surveys showed a preference for Barbarin meat, and sensory tests confirmed that Barbarin meat is more tender, smells better, and tastes better than meat from thin-tailed lambs. But butchers were reluctant to buy Barbarin, and paid farmers better prices for thin-tailed animals. Farmers responded by 'diluting' the fat-tail trait in their flocks.

Global perspective, local action

International research centers can play a key role in two areas: collecting and disseminating information on local coping strategies, and providing technical support to national livestock researchers. For example, ICARDA is developing a framework to integrate data from research studies into community-based breeding plans. Once designed and launched, these plans are implemented by the community with only limited external support. ICARDA is also building R&D networks to link research centers to each other (across the WANA region, as well as globally) to share new technologies.

Livestock producers are already feeling the first impacts of climate change. It is more urgent than ever to scale up research and conservation programs for indigenous breeds, to protect small-scale producers from much more severe impacts in the future.

Back from the brink

The Sicilo-Sarde sheep, developed in Tunisia in the 17th century, is the only specialized dairy breed adapted to North Africa's dry environments. Numbers fell from 200,000 ewes in 1995 to 25,000 in 2000, due to flock tenure changes and indiscriminate crossbreeding with meat-producing rams. In 2003, a local farmer (popularly known as Mr General) formed the Sicilo-Sarde Breeders Association, and acted as the catalyst for a remarkable rescue effort.

Multiple agencies were involved: ICARDA, two national research centers (INAT and OEP), and BOKU. Veterinary staff used an artificial insemination technique known as laparoscopic intra-uterine insemination to halt genetic erosion. Farmers worked with researchers and extension staff to establish a breeding plan to build the population back to viable levels, reduce inbreeding, and increase milk productivity. A milk marketing cooperative was formed. The farmers' association also convinced policy makers to introduce new legislation to support dairy sheep production. By 2007, milk prices rose to over a dollar per liter, and the Sicilo-Sarde became highly profitable. Farmers have shifted from cattle to sheep, and Sicilo-Sarde numbers are increasing rapidly.

The authors are all livestock scientists at ICARDA, Aleppo. Markos Tibbo (m.tibbo @cgiar.org) is a veterinarian and animal breeder; Luis Iñiguez (l.iniguez@cgiar.org) is an animal breeder; Barbara Rischkowsky (b.rischkowsky@cgiar.org) is a small ruminant production specialist.

Livestock Research

for Climate Change Adaptation

Markos Tibbo, Luis Iñiguez and Barbara Rischkowsky

Can animals and their owners adapt fast enough to global warming? Low-cost technologies could be the answer.

ADNAN TERMANINI

It is *the* problem of the 21st century. According to the International Fund for Agricultural Development, climate change will put 50 million additional people at risk of hunger by 2020, and 132 million by 2050. How will climate change impact on livestock production? Changes in temperature, precipitation and glacial run-off will affect not only farming conditions, but also the capacity of the biosphere to produce enough feed for its livestock. Droughts and floods will strike more often. So will livestock disease epidemics. Rising carbon dioxide levels will affect (sometimes positively, sometimes negatively) crop and forage production and rangeland biomass. Feed and water prices will rise sharply, forcing producers to shift from intensive (high input, high output) to less intensive systems.

Without effective adaptation measures, livestock producers – especially small-scale producers, who form the majority – will suffer substantial losses. This article describes how ICARDA is contributing to adaptation measures in the highly vulnerable dry areas of West Asia and North Africa.

The challenges of growth

Small ruminants (sheep and goats) are a major component of the farming system, and an important source of income and dietary protein for the rural poor. They are particularly important in dry areas, because they require relatively small investments, and can be reared on marginal land, converting low-quality feed into high-value milk and meat.

Higher temperatures, lower profits

Scientists at the University of Pretoria in South Africa developed an interesting computer simulation to predict whether cattle farms and small-ruminant farms will respond differently to global warming. The results suggest they will. Cattle farms are likely to suffer, because cattle are not very tolerant to high temperatures. Goat and sheep farms will benefit, because temperature-tolerant breeds are available. The study predicts that a warming of 2.5°C could increase the income of small-ruminant farms by 26%, but decrease the income of cattle farms by 22%.

As temperatures rise further, large farms will shift from dairy cattle and chickens to goats and sheep. Net income will fall for all species, except sheep.

Seo and Mendelsohn, 2007. Climate change adaptation in Africa: a microeconomic analysis of livestock choice. World Bank Policy Research Working Paper 4277.

Between 1960 and 2000, the number of sheep and goats in the WANA region (West Asia, North Africa) increased from 380 million to 660 million. Meat production nearly tripled. Government policies in several countries encouraged producers, traders and proccesors. This growth has generated substantial economic benefits, but has also accelerated rangeland degradation, desertification and loss of plant biodiversity.

Animal numbers will continue to increase (although at a slower rate), because goats and sheep will probably be more profitable than crops, under future climate conditions. The challenge is to manage this growth sustainably.

What strategies are needed?

Over the centuries, farmers and pastoralists have perfected various measures to adapt to variable conditions – seasonal movement of livestock, integrated crop-livestock systems, mixed-species flocks, reciprocal grazing arrangements between communities, adjusting flock size and stocking rate to match grazing resources, building wells and cisterns. These methods worked in the past. They will probably not work in the future, given the pace and extent of climate change that is expected.

Livestock producers need new technologies, training and technical support. Governments need to develop better policies and stronger institutions to manage natural resources sustainably. A combination of these efforts will strengthen adaptation, a term that includes all activities that make people and ecosystems less vulnerable to the impact of climate change, and minimize the cost of natural disasters. Such adaptive strategies could include:

- Identifying livestock species and breeds best suited to future climates; improving heat tolerance in existing species.
- Better livestock management: flock composition, grazing management, rangeland management, production strategies.
- Improving forecasting and early-warning systems.

What can ICARDA offer?

ICARDA's approach to climate change builds on technologies and R&D methods that have proved successful in dry environments – where the impacts of climate change are likely to be most severe. The aim is to strengthen the adaptive capacity of communities and the resilience of rangelands and farming systems to variability and climate shocks.

- Studies on animal biodiversity, to match breeds with specific production environments.
- Wider use of adapted local breeds, improved production systems, more efficient use of feed resources.
- Value addition of livestock products.

Technologies developed by ICARDA and its partners are being used throughout the WANA region. New feed technologies are improving nutrition, milk yields and lambing rates. Community-based breeding schemes are improving breeding stocks. Training programs are helping to ensure that farmers and extension staff are able to use the new technologies effectively.

Low-cost nutrition

In most dry areas, rangelands provide only one-third of the feed that animals need. Supplementary feeding is needed for most of the year, especially if animals are being reared for market. But feed supple-

Health food for animals. Low-cost feed blocks ensure that livestock remain healthy and productive, even when fodder is scarce.

The flow of money. Simple new technologies are helping to add value to milk products, and dramatically increase household incomes.

ments are expensive. ICARDA researchers have developed low-cost options such as 'feed blocks', replacing some ingredients with cheaper alternatives without reducing nutritional value. The feed blocks contain multiple nutrients, and are made from cheap, easily available agro-industrial by-products: tomato pulp, molasses, *burghul* derivatives, crude olive cake, sesame cake, citrus pulp, sunflower cake, and mulberry leaves.

Various combinations have been successfully tested on-farm in Syria, Iraq, Tunisia, Mexico and Central Asia. In one recipe, for example, part of the barley grain in the feed was replaced with molasses and urea. This was used in combination with urea-treated straw (rather than plain straw) for strategic supplementation, i.e. fed to ewes during critical periods in the production cycle. As a result, ewes mated earlier and gave birth at shorter intervals, and lambs were heavier at weaning.

Firmer yoghurt, better cheese

The market for dairy products is growing, but small-scale producers are often unable to benefit, because of quality, shelf-life and marketability issues. ICARDA researchers work with extension staff and farming communities to resolve these problems.

One such study was conducted in the El Bab area in Syria, where sheep milk processing provides 60% of family income. Training programs for women have improved milk hygiene, yoghurt processing and culture management, leading to better quality and higher prices for home-made yoghurt and cheese. For example, their yoghurt was tasty but too soft, often collapsing while being transported over bumpy country roads. They now use proper 'starters' that improve firmness without affecting the taste – and earn an extra 5 Syrian pounds per kilogram.

Research plans

Livestock research, specifically in the context of climate change, will remain a priority at ICARDA. The research portfolio, developed jointly with our partners, includes:

- *Genetics*: Phenotypic and molecular genetic characterization. Improvement and conservation of adapted local sheep and goat breeds. Selection programs for specific adaptive and production traits.
- *Markets*: Improving market access for smallholders. Linking disadvantaged breeds to markets, adding value to their products.
- *Animal health*: Control of transboundary and zoonotic diseases that limit livestock trade and affect human health.
- *Natural resources*: Rangeland improvement and management. Water harvesting to increase the productivity of range vegetation.
- *Feed resources*: Revisiting the research on feeds (by-products, straw treatment, feed blocks, etc). Developing water-efficient forage crops. Use of biotechnology to develop drought-tolerant feed and forage varieties. Widening the use of cactus and shrub 'fodder banks'.
- *Dissemination*: Testing new methods to scale out new technologies beyond pilot areas.

A range of low-cost technologies is available, that can help livestock producers adapt to changed climatic conditions. ICARDA and its partners are now working on two fronts: refining and promoting these technologies, and targeted research on specific issues that are likely to become more important as a result of climate change.

The authors are all livestock scientists at ICARDA, Aleppo. Markos Tibbo (m.tibbo @cgiar.org) is a veterinarian and animal breeder; Luis Iñiguez (l.iniguez@cgiar.org) is an animal breeder; Barbara Rischkowsky (b.rischkowsky@cgiar.org) is a small ruminant production specialist.

Hot Spots of Vulnerability

to Climate Change

Eddy de Pauw

Hot spots on the Silk Road? New mapping methods are helping to identify which areas are most vulnerable to climate change.

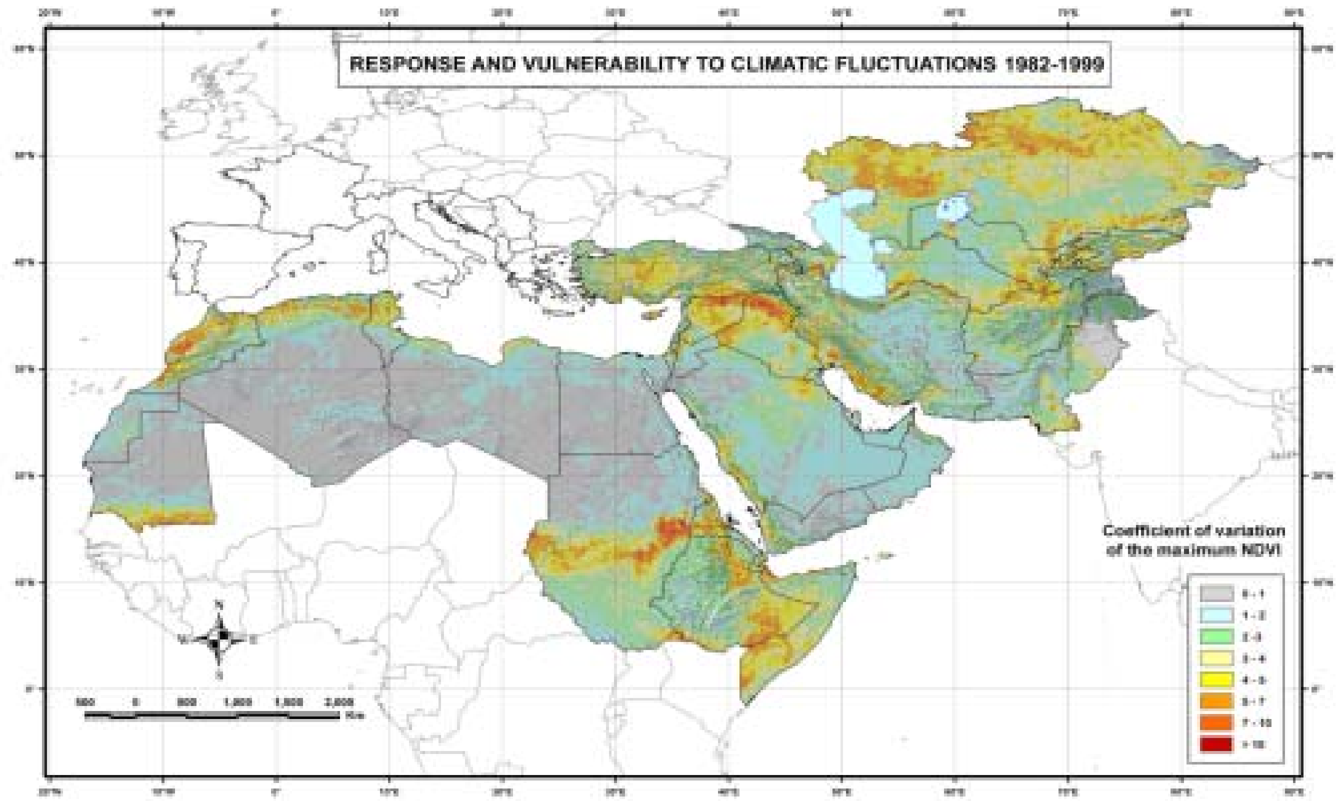
Climate change will affect most parts of the world. Dryland areas (41% of global land area, one-third of world population) will be severely affected. And within the drylands are 'hot spots' of vulnerability, where the largest impacts are expected. ICARDA scientists used GIS analysis, modeling and statistical tools to identify these 'hot spots', enabling scientists and policy makers to focus on the most vulnerable areas.

Space-based science

The CWANA region (North Africa, West Asia, Central Asia, and parts of the Horn of Africa) is the world's largest contiguous block of non-tropical drylands. Images of the region, taken from NASA satellites, were analyzed for the period 1982-2000. The analysis was based on Normalized Difference Vegetation Index (NDVI), which is a numerical measure of the extent of live green vegetation in an area.

A methodology was developed to overcome various problems: distinguishing long-term trends in land cover from short-term fluctuations in biomass caused by year-to-year weather variations, the short time series, and the low resolution of the images (8 km). The images were pre-processed to reduce the effects of cloud cover and correct for noisy spectral signals and sensor drift. They were then 'mosaiced' into a complete coverage of the CWANA region with an appropriate geographical projection. Eventually a dataset was produced showing month-by-month variation in NDVI at millions of locations (pixels) across CWANA.

The hot spot analysis was based on the maximum NDVI, which is a spectral measure of peak above-ground biomass, i.e. crops plus natural vegetation. At any given location, changes in maximum NDVI can be due to changes in land use (e.g. conversion of pastures into crop fields) or to climatic variability. In order to focus on the effects of climatic variability alone, we considered pixels with stable land cover over the period 1982-2000, and then applied a simple statistical measure: the coefficient of variation, or CV, which measures the degree of fluctuation in any parameter – in this case, maximum-NDVI.



Response and vulnerability to climatic fluctuations in the CWANA region, 1982-2000.

The map (above) shows the CV of maximum NDVI over the entire 19-year period, for the whole CWANA region. The red and orange areas have the highest CV, i.e. the largest year-to-year fluctuations in total biomass. This fluctuation is due to current climatic variability, not future climate change. But we know that climate change will lead to greater variability – places where variability is already high will be at serious risk.

Will hot spots get hotter?

The map shows several current hot spots:

- The Maghreb region in North Africa, from Morocco into Tunisia
- The Sahel, from Mauritania into Sudan, Eritrea, northern Ethiopia and Somalia
- The Fertile Crescent: parts of Syria, Iraq and Iran
- The foothill zone north of the Tien-Shan and Pamir mountain ranges in Central Asia
- The rangelands in the north of Central Asia.

All five areas suffer from degradation of land, water and vegetation; periodic droughts, and occasional famines. The future, perhaps, could be even worse. Long-term projections by the IPCC suggest there will be less rain in winter (the main cropping season) in North Africa and parts of the Fertile Crescent. In Central Asia, lower precipitation in key catchment areas will reduce streamflows into the irrigated areas of Uzbekistan, Turkmenistan and southern Kazakhstan, where most of the region's food is grown.

At each of these hot spots, the impacts of climate change – and the vulnerability of rural communities – will be exacerbated by other factors:

- Rapid population growth
- Economies heavily reliant on agriculture
- Acute and growing water scarcity due to overuse.

Three of the five hot spots are critically vulnerable: two 'red' hot spots (Maghreb and the Fertile Crescent) and one 'orange' hot spot (the Silk Road hot spot in Central Asia). These areas are home to tens of millions of families, mostly low-income, small-scale farmers. Considerable international effort will be needed to protect agro-ecosystem resources and livelihoods in these areas – research on climate change processes and impacts, new technologies to increase farm productivity, and policy initiatives to improve livelihoods.

Eddy De Pauw (e.de-pauw@cgiar.org) is an earth scientist and head of ICARDA's GIS Unit. Over the past 30 years, he has pioneered innovative agro-ecological mapping methods in several countries.

Putting Bad Water to Good Use

Manzoor Qadir

Why waste wastewater? Researchers look for ways to use marginal-quality water safely and profitably.

Analysis of the global water cycle yields some encouraging numbers. The world's renewable water supply is about 7000 cubic meters (7 million liters) per person per year. That is higher than the average water availability in the USA, the world's most profligate user. Obviously we have enough freshwater to meet the world's needs, even allowing for future population growth. If only things were that simple...

Most of the world's freshwater is concentrated in specific regions, while large areas are severely water-deficient. Given current demographic trends and future growth projections, up to 60% of the world's population could suffer water scarcity by the year 2025.

Deterioration of water quality, already a global concern, is expected to intensify in resource-poor countries in the dry areas, for two reasons: human activity and climate change. Saline water intrusion in coastal areas is expected to intensify as a result of rising sea levels. Mismanaged irrigation practices in arid and semi-arid regions will accelerate salt-induced soil degradation and water quality deterioration. As more people move to the cities, households and industries will generate increasing volumes of wastewater. And finally, the increased frequency of severe rainstorms will increase the amount of chemicals that run off from farms as well as urban areas.

In sum, freshwater supplies will decrease, and marginal-quality water (saline water and wastewater) will make up a larger share of our water supplies. But can we use this marginal-quality water for agriculture, aquaculture, and non-agricultural uses, or to recharge groundwater supplies? This has been the subject of intensive research by ICARDA and its partners (notably the International Water Management Institute, IWMI) in several countries.

Challenges and opportunities

As populations grow and seek better living standards, more freshwater will be diverted for domestic and industrial use, leaving less for agriculture. The challenge is to increase agricultural production with limited freshwater supplies. The opportunity lies in practical, environmentally friendly ways to use wastewater for agriculture.

Wastewater is already used for food production in many resource-poor environments. Household and industrial wastewater contains a variety of constituents at levels higher than those usually found in freshwater. Irrigation with untreated or imperfectly treated wastewater creates environmental and health risks. Most farmers (and some government agencies) in many developing countries are not fully aware of the consequences.

Wastewater treatment plant in Aleppo province. Wastewater is a potential health hazard – but also a huge opportunity.

The farmer's perspective

Less than 5% (69,000 hectares) of Syria's irrigated area is irrigated with wastewater. But this area, although small, is economically important. Wheat is grown on more than half of the wastewater-irrigated area, together with cotton, faba bean and vegetables, all important cash crops. Syrian law prohibits wastewater irrigation of vegetables that will be eaten raw.

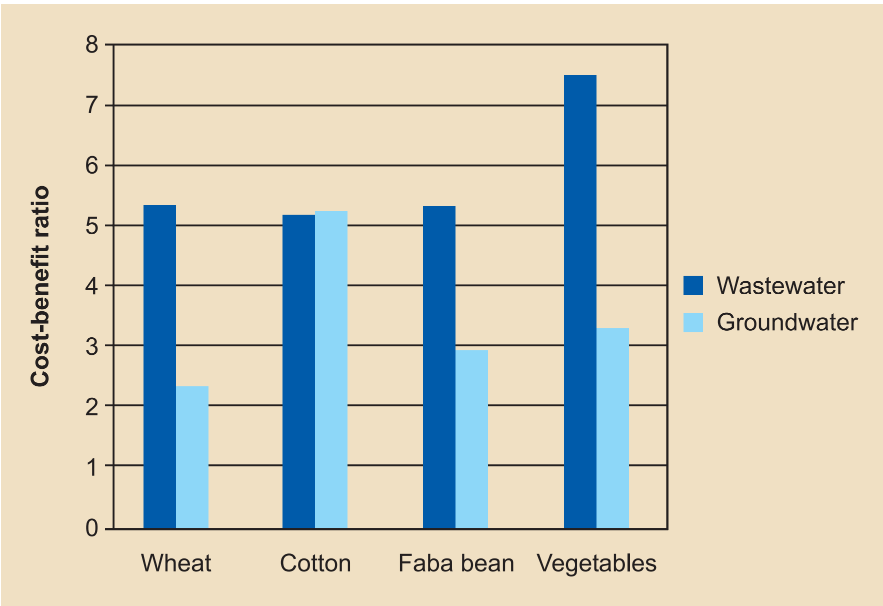
Farmers who have access to wastewater tend to use it despite the health risks and the government restrictions. An ICARDA-IWMI study in Syria's Aleppo region found that many farmers actually prefer wastewater to groundwater, because:

- it is a reliable source of water for irrigation, year-round.
- it contains nutrients, and therefore reduces or eliminates the need for fertilizer.
- it is available nearby; and it's cheaper to pump wastewater than to pump groundwater.

Cost-benefit analysis shows that the farmers are probably right in terms of economic returns, but are putting their health and the environment at risk. Crops irrigated with wastewater give substantially higher returns on investment than crops irrigated with groundwater (see chart). For wheat the farmer's returns, per dollar invested, are $5.31 when wastewater is used but only $2.34 when groundwater is used. The difference is due to a combination of factors: higher yield (the wastewater provides nutrients), lower fertilizer costs ($95 saved per hectare) and lower pumping costs.

More waste, less water

Over 40% of Syria's wastewater is treated before being used for irrigation or discharged into rivers or the sea. This figure is up from about one-third in 2005, because more treatment plants have been built. But that still leaves a huge amount of untreated wastewater, representing a potential health hazard – even though it offers a potential opportunity for small-scale farmers. The country is short of staff with the skills to monitor



Stinking profits? Wastewater irrigation offers excellent returns on investment.

Wastewater is used to grow a range of crops; vegetables are especially popular in peri-urban areas.

and analyze wastes, or to operate and maintain industrial wastewater treatment plants. Building skills is particularly important because responsibilities for treatment, disposal and reuse of wastewater are shared by multiple institutions. This applies to most developing countries, where wastewater collection and treatment are viewed as important, but not necessarily an immediate priority.

Against this background, research (and training) by international centers can play a vital role in promoting the safe use of wastewater. There are several examples. In Kazakhstan, ICARDA led a 5-year study to evaluate the use of treated wastewater from Almaty, the country's largest city, for the production of five tree species: silverleaf poplar, European ash, white mulberry, Japanese quince and dog rose. To further increase the economic benefits, fodder species were planted between rows of trees. Five years of irrigation with treated wastewater had no adverse effects either on tree growth or on the concentration of metal ions in tree tissues. In fact, soil analysis showed that nutrient availability in the soil had increased, because of the wastewater.

In Algeria, ICARDA is working with the International Development Research Centre on wastewater irrigation for wheat. The wheat is primarily rainfed; wastewater is used for supplemental irrigation – small amounts of water, supplied at critical stages of growth, significantly increase yields and water productivity. With successful implementation, this pilot project could be scaled out not only within Algeria but also to similar rainfed areas in other countries.

Wastewater and climate change

Millions of small-scale farmers throughout the world use wastewater for irrigation, but they can rarely control the volume or quality of this wastewater. Researchers and development specialists therefore need to devise low-cost technologies for wastewater use, and identify what policy and institutional support is needed to encourage farmers to adopt these technologies. Key issues include:

- Optimizing the performance of wastewater treatment plants.
- Keeping industrial and domestic wastewater separate, even during treatment.
- Encouraging industries to treat their wastewater.
- Restricting the disposal of untreated wastewater to prevent contamination of surface water.
- Evaluating contaminants in surface and groundwater for health, environmental and food safety risks.
- Monitoring the build-up of chemical pollutants in crops and soils irrigated with wastewater.
- Enforcing national or international standards on wastewater treatment and reuse.
- Evaluating the socio-economic impact of wastewater use on farming communities.

Slow, not Qwaik

Aleppo (population 2.4 million) is the second largest city in Syria. For centuries, the city met most of its water requirements from the Qwaik River, which originates in Turkey. Since the 1940s, there has been continuous extraction of water from the Turkish section of the river; by the 1970s the Syrian part was almost dry. Today the flow rate of the river as it enters Aleppo is less than 1 cubic meter per second. Formerly Aleppo's source of freshwater, the Qwaik River now carries away the city's wastewater.

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Chickpea and Climate Change

Mathew Abang and Rajinder Malhotra

No more falafel? Climate change could lead to a resurgence of the biggest chickpea disease in West Asia.

MAJED KHATIB

Chickpea is grown in over 50 countries. In about half these countries (including all of West Asia and North Africa), it is planted in early spring and harvested three months later. But if it could be sown earlier – in winter rather than spring – the crop could take full advantage of the rainfall in January and February. Winter sowing can *double* chickpea yields, provided two major barriers can be overcome: cold (low temperatures, ground frost) and disease (primarily a fungal disease known as Ascochyta blight). After 20 years of research, both problems were finally cracked a few years ago – or so we thought. Disturbing new evidence suggests that climate change could make hitherto Ascochyta-tolerant varieties susceptible once more.

Ascochyta strikes back

Ascochyta blight is by far the most important disease threat to winter chickpea in the WANA region (West Asia, North Africa). The most favorable conditions for spread of the fungus are wet weather and mild temperatures, typical of late winter or early spring in the region. If the conditions are right, a localized infection can rapidly become an epidemic, destroying the entire crop.

Traditional landrace varieties are highly susceptible, but ICARDA breeders have developed a range of elite lines that are moderately to highly resistant. Four of these lines (Ghab 2, 3, 4 and 5) have been officially released for cultivation by the Syrian government. Others have been released elsewhere in the WANA region.

These lines are resistant at the vegetative stage (the stage during which leaflets appear and grow). Resistance declines as the plant matures, and most lines become susceptible by the time pods begin to form. This doesn't matter too much in dryland areas, because at this stage (April-May), rain is highly unlikely, and there is little risk of large-scale infection under dry conditions. But all this could change.

Climate change models suggest two things. First, a higher probability of late-season rains, and therefore of Ascochyta infection. Second, more intense 'extreme' events – in this case, rainfall above a critical threshold, potentially leading to a blight epidemic.

Is this a genuine threat or simply a possible scenario? Researchers from ICARDA, the University of Aleppo in Syria, and the Department of Agriculture and Food, Western Australia, analyzed 29 years of data (1979 to 2007) collected from ICARDA's research station in Tel Hadya, Syria. The 29 years fall into two distinct periods, 1979-2000 and 2001-07, with marked differences in weather conditions, and in the frequency and severity of pod infections. Conditions during the latter period favored infection and spread of Ascochyta blight. For example, compare the month of May (a criti-

MAJED KHATIB

Storm warnings? Weather data from ICARDA's Tel Hadya station shows changing rainfall patterns that could favor some disease pathogens.

The battle against blight

Ascochyta blight is the world's most important chickpea disease. It is caused by a microscopic fungus known as *Ascochyta rabiei*, which releases spores that can lie dormant in the soil for a year or more, and then attack seeds when conditions are right.

The first symptoms of ascochyta blight are small reddish brown spots (lesions) on the leaves and stems. The spots enlarge and change color: light brown, dark brown, or yellowish with a dark outer ring. As the disease progresses, leaves begin to wilt. The lesions on the stem produce small, black fruiting bodies known as pycnidia, which can be seen with a hand lens. Under humid conditions, spores ooze out of these pycnidia and are spread to surrounding plants by rain droplets. Occasionally lesions grow, coalesce and even girdle the stem – effectively killing off the portion of the plant above the girdle, or at least making the stem weak and prone to breaking. Infected seeds are shrivelled and discolored; not severely poisonous, but completely unsaleable.

ICARDA has developed an effective, low-cost integrated management package to control the disease. The package combines various components: a resistant or tolerant variety, use of high-quality seed pre-treated with fungicide, crop rotation (to avoid fields with infected debris), delayed sowing (to ensure that humidity is low when plants are most vulnerable), weed control, more widely spaced plants (therefore less humidity within the plant canopy). Chemical fungicides are still necessary, but should be used judiciously: one preventive spray at the vegetative stage and a second spray if rainy or humid weather continues.

cal period in relation to blight infection) during the two periods. The latter period was about 1.5°C hotter, with nearly twice as much rain on average, compared to the period 1979-2000.

The Department of Agriculture and Food, Western Australia, has developed a model that predicts the onset and seasonal pattern of ascospore release: when does the fungus release spores, and how fast do the spores spread, under different weather conditions? Using the model, we ran simulations to compare the critical crop stages (flowering and podding, roughly April to mid-May) during the two periods, i.e. 1979-2000 and 2001-07. The simulations showed that during these critical stages, ascospore load was 60% higher, the number of ascospore release events 35% higher, and disease pressure index twice as high during 2001-07 compared to the earlier period.

The critical factor was monthly rainfall. Earlier studies have shown that blight epidemics occur when rainfall exceeds a critical 'threshold' of 40 mm per month. Below this threshold, the fungus does not severely attack chickpea pods. In the current study, this threshold was crossed twice in 29 years, in 2001 (90.8 mm) and 2007 (53 mm). These were the only years in which severe pod infection was recorded. This suggests that climate change might increase the frequency of blight epidemics by breaching an environmental 'barrier' – the 40 mm threshold that has previously restricted the pathogen's development during the critical podding stage, when plants are most vulnerable.

Chickpea field trials at Tel Hadya. The aim – new varieties that wll remain Ascochyta-tolerant under a changed climate.

	1979-2000	2001-07
Temperatures in May (°C)	Mean 18.2-22.6	Mean 19.7-23.8
	Max 26.7-30.9	Max 28.2-31.9
	Min 9.6-14.3	Min 11.3-15.6
Rainfall in May (mm)	Range 0 to 36.9	Range 0.6 to 90.8
	Average 13.7	Average 26.9
Ascospore load (%) *	10.7	16.1
Ascospore release events *	8.6	11.6
Disease pressure index *	0.74	1.56

* during the critical 6-week period in April and May

It is usually difficult to establish a causal relationship between climate change and local biological trends, but we found a clear mechanistic relationship between climate trends (hotter, wetter) and the host-pathogen interaction. If this relationship can be confirmed with more data from different sites, the implications are clear. The impacts of climate change on agriculture will be felt much sooner than we expected.

To help mitigate the impact, plant breeders might need to develop chickpea varieties that are resistant to Ascochyta not only during the vegetative stage but also during the pod/seed stages. That would help consolidate the switch from spring to winter sowing; improve food supplies in a region that relies heavily on food imports; and enable small-scale farmers in West Asia to protect a key source of income.

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Livestock Mobility
and Climate Change

Celine Dutilly-Diane

Pastoralists and their flocks must keep moving, to stay one step ahead of the weather. How will climate change affect this mobility?

Most livestock in the developing world are found in dry rangeland areas, where supplies of grass and water are sparse, widely scattered, and highly variable. Over the ages, pastoralists have learnt to cope with these conditions. The key is mobility: regular long-distance seasonal migration, combined with local migration for short periods.

Climate change will lead to more scarcity and greater variability, so mobility will become more important than ever. But paradoxically, many pastoral communities are becoming less mobile – leaving them more vulnerable to the impacts of climate change. This article looks at what factors are hindering livestock mobility, and how scientists and policy makers can help.

Settling or unsettling?

The process of 'sedentarization' began with colonial governments, which encouraged pastoralists to settle down and grow crops in rangeland areas – which were usually ecologically unsuited for permanent agriculture. This trend continued with post-independence policies (e.g. subsidies for fertilizer, fuel or tractors) aiming to boost food production. And even policies designed to protect pastoralists, such as feed subsidies in drought years, had unintended consequences. Earlier, flock sizes were adjusted to match climatic conditions. Now, flocks increased continuously, to levels far beyond the land's carrying capacity.

Another factor was intensification of production systems. The introduction of feed supplements in the mid-20th century changed mobility patterns throughout North Africa and West Asia. Once, flocks depended almost entirely on the rangelands, and mobility patterns were dictated by the availability of forage and water. Today, rangelands provide only one-third of total feed requirements, and mobility patterns depend mainly on the availability of crop residues and the price of animal feed.

Mobile cisterns are becoming increasingly common in many dry areas. Instead of flocks moving to water, water moves to the flocks.

More research needed

A recent study in Syria (see box) shows that 85% of the country's pastoralists rely, partially or completely, on mobility. But some mobility patterns are under threat. The livelihoods of millions of poor livestock producers could suffer, unless innovative solutions can be found.

The first step is to better understand the interactions between feed requirements, movement patterns and social structures. There is a large body of mainly anthropological literature on traditional Bedouin society, including the Hema system of range management. Pastoralists are rapidly changing their livestock management strategies, but the current practices are rarely documented. More research using GIS tools and simulation models, combined with socio-economic and anthropological work, could help monitor mobility patterns at different geographical scales, and improve the management of livestock and rangelands.

Unmoving with the times

Changes in mobility patterns are complex. Some communities or households have moved towards more intensive, market-oriented production, with largely sedentary flocks and heavy use of feed supplements. But others who still rely on traditional pastoralism find that mobility is being hampered.

With growing pressure on grazing land, communities are less willing to accept 'visiting' flocks. And traditional institutions that used to regulate land use and manage conflicts (within the community and with neighboring/transhumant herders) have been weakened by decades of centralized management and by the unintended consequences of land reforms: whether granting of private tenure or the other extreme, nationalizing communal land.

Recent work by ICARDA and CIRAD-France, in collaboration with national research centers, has provided some interesting results, and highlighted areas where more research is needed. In Syria, we are studying the influence of climatic, economic and social factors on mobility patterns, and the evolution of traditional conflict resolution mechanisms. In Morocco, we looked at dominance and power relationships among pastoral groups who share a large rangeland, and the effects of such relationships on productivity, incomes and range management.

Legal and policy frameworks

Any solution must rest on an adequate legal framework to protect 'mobility rights'. Mauritania, for example, has created new legislation, in consonance with traditional custom and Islamic Sharia law. One key element is to correct the pro-crop bias in land tenure law, by lifting some of the restrictions (placed by owners of crop fields) on migrating herds. The legislation was promulgated in 2000, but is yet to be fully implemented. Several other countries in West Africa – Guinea, Mali, Niger, Burkina Faso – have drafted or implemented similar policies, but these efforts are only about 10 years old, and it is too early to evaluate their effectiveness.

Once an effective legal framework is in place, policy makers must address three key issues. First, correct the policy bias. In most countries in West Asia and North Africa, incentives are biased toward crop production and against livestock. And livestock policies themselves are biased in favor of intensive production, and against migrant pastoralists – who are usually the poorest section of society.

Second, enact policies to improve rangeland quality. This would have multiple benefits, including partly compensating for reduced mobility. In Southern Tunisia, for example, the government provides incentives to encourage 'resting' of rangelands to allow natural vegetation to recuperate. Herders who rest private rangelands receive barley grain for their animals (equivalent of $8.30 per hectare of rested land) each season. Communities with collective rangelands receive funds for infrastructure. For example, if a community rests 100 hectares of land, it receives $830, which can be used to dig a well or create a shelter where flocks can rest.

Third, provide exit strategies. With growing pressure on rangeland resources and more barriers to livestock migration, many households will find that pastoralism is no longer viable. Government support – education, training programs, subsidies for small-scale agribusiness – could help the younger generation move out of pastoralism, or even out of agriculture altogether. That would reduce the pressure on rangelands, and enable the remaining pastoralists to improve productivity, output and incomes.

Many studies have shown that pastoralists respond quickly to external changes, whether positive or negative. By implication, policy reforms and new technologies can be developed and adopted quickly. Higher temperatures and greater rainfall variability will pose severe problems for livestock owners in dry areas. But pastoralists have always been flexible and resilient. With a little help, they can continue to survive in difficult environments – and even provide the world with lessons on how to cope with climate change.

Mobility patterns in Syria

A joint study by ICARDA and the Syrian Ministry of Agriculture examined mobility patterns in Syria's rangeland areas (*badia*), through household and ecological surveys covering 50 communities across the country. Over 85% of *bedouin* migrate periodically, between different *badia* areas, or between the *badia* and the higher-rainfall cropping zone. Most flocks spend the winter (the rainy season) in the *badia*. Migration decisions are made in spring. If the rains have been good, many flocks remain in the *badia* year-round. Otherwise, they move to the cropping zone to feed on crop stubble and residues; herders often rent harvested fields for grazing.

About 12% of households use their home site only in good years. Another 30% are 'commuters', typically making two round trips per year between the *badia* and the cropping zone. The rest spend several months in the *badia* each year; and about 12% rarely leave the *badia*, even in drought years.

Climate change will affect mobility in all groups. It will reduce biomass availability in rangelands, so the more mobile households (e.g. the commuters) are likely to remain in the cropping zone for longer periods. Households that are less mobile (more dependent on the *badia*) will increase their frequency of migration into the cropping zone.

Trasnhumance has been practiced for centuries. But it's growing harder to maintain equity – and avoid conflict – between farmers and pastoralists.

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Adapting to Climate Change:
Insights from the West African Sahel

Camilla Toulmin and Saleemul Huq

Sometimes, change isn't as hard as we imagined. Lessons learned in West Africa could help other developing countries adapt to climate change.

The climate change debate has moved substantially over the last couple of years, from a single focus on achieving major cuts in greenhouse gas emissions to addressing the inevitable consequences of global warming. There is a broad consensus that adaptation will be critical, and that we will need to find ways to support communities, particularly in the developing world, adapt to climate change. Adaptation will be required at multiple levels: vulnerable communities (e.g. those living in areas prone to flood, drought or hurricanes), vulnerable sectors (e.g. water resources, coastal areas, the health sector), at national level (e.g. poverty alleviation or disaster management strategies), and at international scales (e.g. shared river basins).

Most of the resources needed for adaptation will have to come from the countries themselves, but the international community can provide developing countries with technical as well as financial support. Actions to help adaptation are not completely new or unfamiliar. Already well-established development practice will also improve resilience and reduce vulnerability to climate change, and improve natural resource management.

Lessons from West Africa

The West African Sahel, a belt of semi-arid land along the southern edge of the Sahara desert, shows what 'adaptation' means in practice. Since the late 1960s, the Sahel has experienced a 25% decline in rainfall compared to the previous period, as well as several severe droughts. In response, farmers have shifted to shorter-cycle varieties of millet and maize, and abandoned crops like groundnut that need higher rainfall. Livestock have been herded further south, away from the desert margins and into settled, cultivated areas, where a new accommodation between animals and crops must be sought. Wells have been dug and small dams built to irrigate gardens of onions, tomatoes and mangoes that are grown for sale.

Many farmers have also moved southward, seeking land in better-watered areas. Since the late 1960s, five million people from Burkina Faso and Mali have migrated south to neighboring Côte d'Ivoire. Much of the civil strife there today stems from the uneasy relations between immigrants and local people, and the growing shortage of land in a region where it had formerly been considered in endless supply.

What does the experience from the Sahel tell us? People adapt to changes in climate, but adaptation is not cost-free. Governments can help or hinder adaptation: they can enable movement across borders; make local institutions stronger and more transparent so that outsiders can gain access to land; and offer technical and financial support for small-scale irrigation. They can provide more reliable channels for migrants' remittances, which have become vital for many families. But overall, governments in the Sahel have played only a limited role. Rather, it was people, their families, communities and local institutions, who developed innovative ways of adapting to climate change.

The adaptation agenda

First, the rich world must recognize that it has been largely responsible for climate change, and address problems of adaptation, particularly in Africa. Some funds have been allocated, but the sums involved are tiny in relation to the need. Once we admit that rich countries are at least partly responsible, we can no longer adopt the 'lady bountiful' approach of providing charity to those suffering from global warming. Instead, there are strong grounds for payment of reparations. Giving small amounts of aid is the preferred course for most rich country governments – allowing them a warm glow of self-righteousness, while avoiding the much harder task of undertaking domestic measures which could lose votes, or damage the interests of powerful groups such as the oil and gas industry.

Agroforestry park in Mali – less erosion, more fuel and fodder. The park, established with NGO support, is managed entirely by the community.

Second, industrialized countries must live up to the Kyoto agreement on cutting greenhouse gas emissions, and start planning for major additional emissions cuts beyond Kyoto, which ends in 2012. This is crucial, because credibility must be built, as a prerequisite to engaging developing countries in future mitigation efforts.

Climate change and development policy

Third, we need to understand what 'adaptation' means, and how to strengthen local capacity to cope in ways that bring tangible rewards to local people. In many places, communities and local organizations are already doing a great deal in terms of adaptation. Non-governmental groups can support these efforts, rather than waiting for governments to make things happen. One good example is the rapid spread of natural tree regeneration across the drylands of the Sahel. This has made land use patterns and livelihoods more resilient, strengthened biodiversity, and sequestered substantial amounts of carbon. NGOs and other civil society groups can play a major role to support local action of this sort.

The cost of adaptation – who pays, and how

Adaptation to climate change will involve large-scale efforts at multiple levels, with multiple players. How much will this cost? Some least developed countries (LDCs), after preparing national plans for climate change adaptation, have identified the most urgent needs, which vary between $100 million and $200 million per country. The World Bank estimate is $10 to $40 billion per year for all developing countries. This is an approximate, 'back of the envelope' calculation, being refined by an ongoing study.

Most of the resources will have to come from the countries and communities themselves, but international assistance can and should play a major part. The UN Framework on Climate Change has created several new funds, including the Special Climate Change Fund and the LDC Fund, which are based on voluntary contributions from rich countries. These funds have raised several hundred million dollars so far. Another fund under the Kyoto Protocol, called the Adaptation Fund, is not based on donations but on an automatic levy of 2% on transactions under the Clean Development Mechanism (CDM). This fund is just establishing itself, but has the potential to be a major new vehicle to support adaptation activities in developing countries. More climate funds are being set up, such as the World Bank's Climate Change and Resilience Fund, the UK's Environmental Transformation Fund and the Norwegian government's Forest Fund.

Some governments have begun using overseas development assistance (ODA) funds to support adaptation activities. There is a case for arguing that ODA should include support for adaptation. But the obligation for rich countries (the principal greenhouse gas emitters) to help poor and vulnerable countries is not based on ODA but on the principle of 'polluter pays', which is enshrined in the UN Framework on Climate Change. Therefore, while funds could be delivered through aid agencies, the money should not be part of ODA – it should not be charity, but rather an obligation, as compensation for damage done.

Fourth, climate change resilience must be built systematically into new projects and policies. To date, climate change is almost never used as the template within which to make choices between options. Yet, whether it is river basin management, a new irrigation system, or urban planning, the implications of climate change must be a primary consideration.

Fifth, strengthening local land rights and encouraging investment in sustainable management will help farmers adapt to lower rainfall. In many cases, this means improving local technologies for soil management, like the simple terracing methods that have transformed the central plateau of Burkina Faso. Governments also need to provide incentives for collective management of common resources such as water, grazing and woodlands, through joint management, legislation and local by-laws.

Sixth, monitoring and lesson learning across the continent can help transfer successful local innovations from one area to another. The Kyoto Protocol offers the opportunity to combine climate mitigation measures with socially beneficial outcomes, to earn a 'development dividend' on activities funded through the CDM. International help to encourage South-South learning on resilience and adaptation could lead to huge benefits.

Technologies for the future

Seventh, investment is vital in the design of new and better energy systems, through decentralized power generation, selective use of biofuels and improvements in solar technology. This must become a high priority. The challenge is not just to develop new technology, but to design agricultural production systems centered around local livelihoods, to address the risk of biofuels driving small producers off the land.

Finally, the rapid growth in urban centers across Africa needs clever thinking to provide institutional and technical innovations in energy, shelter and transport. Over the next two or three decades, over 90% of global population growth will take place in the big cities of the developing world. These mega-cities face enormous challenges in becoming more environment-friendly and less vulnerable to climate change, reducing vulnerability of the urban poor, and ensuring the welfare of future generations.

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On-Farm versus Off-Farm: the Choices for Policy Makers

Aden Aw Hassan and Pieter De Corte

Jobs, incomes and agriculture. How will climate change impact on the poor, and what should policy makers do?

Farming in dry, marginal areas is usually a high-risk, low-profit enterprise. To make ends meet, households must supplement farm income with income from off-farm sources: remittances, a part-time job, or a small business. As urbanization and rural-to-urban migration increase, the opportunities for (and importance of) off-farm income will also increase. Simultaneously, given the likely impacts of climate change, incomes from small-scale farming will become smaller and less reliable.

That raises the question: Given these trends, should poverty alleviation programs continue to focus on agriculture? Or should they focus on creating more off-farm income opportunities in rural areas?

In theory, off-farm income can play a crucial role in cushioning the rural poor against the impacts of climate change. But in practice, opportunities for off-farm income are scarce – and will remain scarce – for precisely those communities that need them most. There will always be some off-farm opportunities for a few people in any community. But for these opportunities to be available to a significant number, various preconditions must be met: roads, markets and other infrastructure, appropriate policies, education, and availability of credit to would-be entrepreneurs.

A recent study by ICARDA and the Université Catholic de Louvain in Belgium suggests that these preconditions will not be met in many areas that are poor, marginal, and vulnerable to climate change impacts. By implication, climate change makes it even more urgent to invest in agricultural R&D in these areas.

The study was conducted in El Bab district in north-west Syria: a typical marginal area, with rainfall of 200-300 mm per year, and mostly rainfed agriculture. The study covered a range of issues. Here we focus on mainly on household income.

Off-farm income

What opportunities are available for earning off-farm income? One-third of the households in El Bab reporting off-farm income are in fact talking about remittances from family members who have migrated, either to the cities or outside the country (mainly Saudi Arabia, Lebanon and Jordan).

The remaining two-thirds of off-farm income earners work mainly on low-paying and/or short-term jobs. Over half of all jobs are temporary, available only for a few months in the year. One-third of the jobs are low-paying *and* temporary. Only one-third are stable jobs offering reasonable wages – and interviews with the community revealed that access to these jobs depends on education and social connections, which most people lack.

The study classified households into three main groups:

- About 18% of the rural population are 'specialist' farmers who rely very little on off-farm income. These are relatively wealthy households, with adequate land and access to irrigation and credit.
- About 30% combine farming with off-farm work. Some are mainly farmers who work in the off-season, others are mainly laborers with a small plot of land or a few sheep.
- About 35% are landless households, relying exclusively on off-farm income.

The third group is the worst off. Although they rely mainly on wages, their skill levels, education and 'social capital' – and therefore their wages – are the lowest. Poverty head counts in this group are nearly double those in the other groups. Most of these households have little chance of building savings and assets. For example, 44-52% of households in the two upper groups can potentially save at least $1000 per year. Only 18% of the third group can save this much – in fact, 70% spend more than they earn.

This furniture workshop in El Bab employs about a dozen people, mostly relatives of the owner. As in most rural areas, jobs are scarce and low-paying.

The solution: agriculture

How to lift these households out of poverty? Building education and skills are essential, but will require sustained government investment over many years. In the shorter term, and as a complement to longer-term efforts, the solution is to develop appropriate technologies: drought-tolerant crop varieties, soil and water management methods, low-cost technologies to improve animal health and nutrition or add value to farm produce.

Such technologies are already available. But we need to strengthen policy and institutional support to encourage farmers to adopt them. We also need to ensure that seed is available, on time and at reasonable prices; and that small-scale farmers can obtain small loans or agricultural credit. And finally, we need to create employment in rural areas, whether in farming, agribusiness or elsewhere.

From past experience, we know two things. First, in poor, agriculture-dependent economies, growth must begin with agricultural development. Second, investment in agricultural R&D, extension and policy support not only improves farm incomes but also creates ancillary jobs and new opportunities for off-farm income. Climate change is likely to increase risk and reduce profitability of small-scale agriculture in developing countries. The solution is not less investment in agriculture, but more.

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Climate-Proofing:

Practical Tips on Farm Management

Jürgen Diekmann

No farm is climate-proof. But simple management methods can minimize the damage caused by extreme weather events.

Climate change in the Middle East is expected to increase the risk of extreme weather: drought, rainstorms, water-logging, frost, high temperatures. These factors are outside the farmer's control. But the use of sound agronomic practices can help reduce the risk of climate-related crop losses, and ensure good harvests despite climate change. This article provides practical farming tips.

1. Soil health

Maintain or improve organic matter. Instead of burning plant residues, keep them on the field, or return them to the field as compost, together with animal dung.

Reduce soil compaction. Excessive compaction limits root growth, reducing yields. It also reduces water infiltration rates – which means that during strong rainstorms, much of the water is lost as runoff. To reduce compaction during field operations:

- Use the lowest possible machine weights.
- Use maximum size tyres, with the minimum required air pressure.
- Avoid traffic on wet soils.
- During the harvest, do not use a trailer within the field; keep it on headlands or adjacent field roads.
- Reduce traffic on fields by combining operations (e.g. seedbed preparation + planting).
- Introduce 'tram lines', so that traffic in the field throughout the season is restricted to certain tracks.

2. Tillage

Reduce tillage as far as possible. This minimizes evaporation from the soil surface, and also reduces loss of organic matter. Any tillage should be done when the soil is dry, for best effect and less compaction. Ideally, tillage should be done soon after the harvest. This will reduce the amount of residual grains or nesting material available to rodents. The aim of tillage/seedbed preparation is to have a field surface as level as possible.

This makes harvesting easier – in a dry season, when plants remain short; or in a wet season, when lodging (plants falling over) is a problem.

3. Planting

Plant early, at shallow depth, with low seed rates and rows close together. Early planting enables the crop to make full use of available moisture and to use the full length of the optimal growing period. The crop also matures slightly earlier, i.e. the critical grain-filling stage is completed before the later part of the season, when high temperatures and drought are likely. Lentil is a good example: although it is fairly drought tolerant, plants shed their flowers if temperatures remain above 27°C for extended periods.

Shallow planting means plants emerge faster (provided moisture is available). Traditionally, farmers planted late – which made sense in the days when herbicides were not available. Some farmers also worry that early-planted crops could suffer drought damage. But this risk is minimal; it has not happened even once in 30 years of early shallow planting at ICARDA.

Low seed rate, combined with early planting, allows the plant to adjust crop density by producing more tillers or branches, thus achieving the same yield at lower cost. In a drought year, high seed rates will lead to a higher percentage of plants dying out, which is a waste of seed and moisture. Lower seed rates lead to self-regulated, possibly thinner stands. Closely spaced rows ensure that the leaf canopy closes earlier, intercepting sunlight more efficiently and preventing the soil from drying out due to direct sunshine and wind.

4. Rolling after planting

Rolling provides several benefits. It improves contact between seeds and soil particles, leading to faster, more uniform germination. It levels the surface, making it easier to harvest short crops (this is important during very dry seasons), and enabling mechanical harvesting even of lodged crops. Rolling also pushes stones below the soil surface, thus protecting combines from being damaged during harvest.

Always use tram lines, to minimize traffic and soil disturbance during the crop season.

About half of precipitation evaporates from the soil surface. Only the remaining half is available to plants for transpiration and growth.

5. Varieties

The varieties used must be tolerant to abiotic stresses: drought, waterlogging, cold (which can occur either early or late in the season) and high temperatures (mostly late in the season).

Plant architecture with good shading ability (prostrate growth) is preferable. For example, consider two otherwise similar, high-yielding bread wheat varieties, Babaga and Cham 4. Babaga is a prostrate type, with leaves that shade the ground fairly well. Cham 4 has more upright leaves, permitting the sun to reach the ground, and is therefore limited to wetter areas.

In legumes, particularly lentils, the height of the lowest pods is an important factor for mechanized harvest, especially in dry years, when plants remain short. Choose varieties with sufficient lowest-pod height, to minimize losses at the combine table.

6. Rotation

To avoid soil-borne problems crop rotations should be as long as possible, e.g. 6-year rotations instead of 2 years. In dry areas, the most important criterion when choosing a rotation crop is the water requirement. It is impossible to foresee at planting time whether the coming season will be dry or wet. Buffering the moisture requirement by rotating crops with high and low water demand reduces the chances of extreme water stress.

For example, a wheat crop at ICARDA's Tel Hadya farm yielded 5 tons per hectare during the 2005-06 season, which was the second consecutive dry season. This was possible only because the previous two crops on that field had low water requirements.

7. Residues

In order to recycle nutrients and store water as much as possible in the rooting zone, avoid burning of straw and other residues. Burning is illegal in many countries. Better options are:

- Use it as animal feed and return it to the field as dung or compost.
- Leave it on the surface, particularly in zero-till systems.
- Harvest the residues, chop them up, and then plow them into the soil using a ducksfoot cultivator or plow.

How to flood-proof a field

Two parameters are important:

- **Percolation/infiltration capacity.** Flooding will occur if the infiltration rate is lower than the rate of precipitation or water inflow. Any compaction in the top layer reduces the infiltration rate. Zero-tillage soils tend to have less compaction and therefore better infiltration.
- **Run-off.** Any field with a slope has a risk of runoff. As long as the slope is fairly low, runoff can be minimized or even eliminated by keeping the infiltration capacity as high as possible. Raindrops splashing on naked soil reduce the soil's infiltration capacity and sometimes create immediate runoff. Maintaining ground cover (leaving some plant residues on the field) will reduce the splashing effect of heavy rains, and reduce runoff. Following contour lines during all operations – particularly tillage, planting and harvest – will help reduce runoff and also control erosion.

Make the right choice

Several technologies can help improve yields and soil health. But every technology has its advantages and disadvantages. Make sure you choose wisely.

Reduced tillage can reduce wind and water erosion, provided the soil is not compacted by excessive traffic, and does not have a 'tillage pan' (which is often created when a moldboard plow or a disc harrow is used). Both problems are common when mechanical equipment is used on wet soil. On the other hand, reduced tillage may increase the need for herbicides – you can eliminate tillage or herbicides, but not both. This issue is important for farmers who are targeting the organic market.

Mechanization can increase the farm's working capacity. But if done incorrectly or at the wrong time (e.g. during a wet period), it can lead to erosion, compaction, or loss of organic matter.

Irrigation. Various methods are available. Flood irrigation is the least desirable, because of high water use, over-irrigation (especially in parts of the field close to the water inlet/intake), and a high risk of erosion. Standard sprinkler/pipe systems are reasonably good, if operated properly. Drip irrigation devices save water, because they minimize evaporation losses: water is not misted through the air, nor is the soil surface flooded, eliminating the 'easy' ways for evaporation to occur. Timing of irrigation is important. The hotter and dryer the climate, the more important it is to irrigate in the evening or at night, in order to reduce evaporation losses.

Do not burn crop residues. The benefits (e.g. weed control) are more than outweighed by the loss of potential nutrients.

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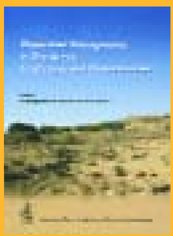
New publications

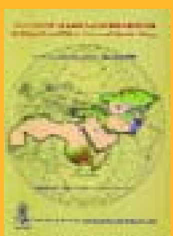


Watershed management in dry areas: challenges and opportunities. Adriana Bruggeman, Mohamed Oussar and Rabi Mohtar, eds.

Proceedings of a workshop, Jan 2005, Tunisia. Presents results from Algeria, Morocco, Tunisia, Yemen and USA, under a joint project by IRA-Tunisia, Purdue University and ICARDA. The papers cover hydrology, modeling, water harvesting, water table recharge, and community-led approaches to watershed management.

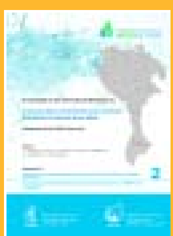
Harnessing biotechnology and genetic engineering for agricultural development in the Near East and North Africa. Michael Baum and Kakoli Ghosh, eds.

Proceedings of a policy dialog meeting, Feb 2006, Egypt. Reviews the current status of biotechnology research and biosafety regulations in the NENA region. Includes papers on field evaluation of transgenic plants, and public perceptions and policy concerns relating to biotechnology.



Assessment of land cover and land use in CWANA. David Celis, Eddy de Pauw and Roland Geerken. Part 1. Land cover and land use, base year 1993. Part 2. Hot spots of land cover change and drought vulnerability.

Outputs from a collaborative project by ICARDA and Yale University, focusing on Central Asia, West Asia and North Africa. Part 1 describes a methodology for rapid assessment of land cover and land use (LCLU), using GIS analysis of low-resolution satellite imagery. Part 2 analyzes LCLU changes over an 18-year period, and identifies areas most vulnerable to degradation. Crucially, the method distinguishes between degradation caused by human-induced processes, and that caused by natural climate fluctuations.

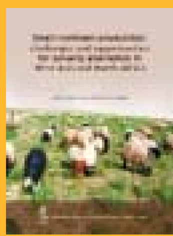


Improving water productivity and livelihood resilience in the Karkheh river basin, Iran. Hamid Farahani et al., eds.

Proceedings of a workshop, Sep 2007, Iran. Describes biophysical and socio-economic conditions in the Karkheh basin, technologies for increasing water productivity, approaches for technology dissemination, and case studies conducted in the basin.

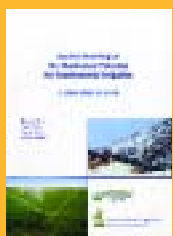
Seed production of cool-season food legumes. Zewdie Bishaw and Anthony van Gastel.

A comprehensive manual for faba bean, lentil and chickpea seed producers in developing countries. Covers various aspects, including variety descriptions, seed production, treatment and storage, and quality assurance.



Small ruminant production: challenges and opportunities for poverty alleviation in West Asia and North Africa. Aden Aw-Hassan, Farouk Shomo and Luis Iñiguez.

Analyzes trends in small-ruminant meat production, consumption and trade in the WANA region, the factors driving these trends, constraints to sector development, and availability of technologies and institutional support for small-scale livestock producers.



Spatial modeling of the biophysical potential for supplemental irrigation. Eddy de Pauw, Theib Oweis, Bashar Nseir and Jawad Youssef.

A case study in Syria. Describes a GIS-based modeling methodology for identifying potential areas where supplemental irrigation can be introduced. This can significantly improve the water productivity of rainfed crops in dry areas.

Farmers' performance criteria for new barley varieties and their diffusion through farmer-to-farmer seed distribution. Ahmed Mazid, Aden Aw-Hassan and Hisham Salahieh.

Tracks the diffusion of new barley varieties, following an initial distribution of seed to farmers in 24 villages in Syria. Also examines farmers' trait preferences, criteria for adopting new varieties, and the implications for research and policy.

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