



Adapting Agricultural Systems to Climate Change

The performance of crops, wild plants, livestock and aquatic resources under stress depends both on their inherent genetic capacity and on the whole agroecosystems in which they are managed. For that reason, any serious effort to increase the resilience of developing country agriculture in the face of climate change must involve the adoption of climate-resilient crop varieties and animal breeds as well as more prudent management of crops, animals and the natural resources that sustain their production while providing other vital services for people and the environment.

Using the knowledge and technology emerging from research carried out by the Centers supported by the CGIAR and many other organizations, farmers and other land users are making significant shifts in current practices. Such changes, already imperative, will become even more so in the coming decades, as the consequences of climate change unfold.

Climate-Resilient Crops

If farming communities are to adapt successfully to climate change, they will need crop varieties with greater tolerance to stresses such as drought and heat. Since those stresses have always posed a significant threat to crop production, CGIAR scientists began developing hardier varieties soon after the international agricultural research centers were created. "Climate-resilient" varieties resulting from this work have already reached farmers' fields, and more are in the making.

New scientific tools are proving to be helpful in speeding improvement. One consists of techniques from molecular biology, which enable plant breeders to identify and select for genes controlling stress tolerance with far greater efficiency. Such techniques are especially important for successfully transferring desirable

traits from wild plants related to crops into commercial varieties of the domesticated species. A second set of tools involves farmer participation in plant breeding, which is highly effective for ensuring that crop improvement takes account of valuable local knowledge and gives results that are truly relevant to local needs and preferences.

Drought-tolerant maize for the tropics: Drought reduces global maize yields by as much as 15 percent annually, representing crop losses of more than 20 million tons of grain. As part of a worldwide effort to curb these losses, scientists with the International Maize and Wheat Improvement Center (CIMMYT) are working with national partners in sub-Saharan Africa to develop drought-tolerant varieties. So far, more than 50 such varieties have resulted from this work, and are being grown on a total of about one million hectares.

Part of the secret behind this triumph is a novel breeding method in which hundreds of small farmers take part in testing new varieties under harsh growing conditions. Varieties selected on the basis of field testing at nearly 150 stress-prone sites in Eastern and Southern Africa yield 20 percent more, on average, than the ones they replace. In search of further yield gains, CIMMYT scientists are identifying areas of the

maize genome linked to drought tolerance, with the aid of a molecular genetic map, based on data indicating the performance of different types of tropical maize in diverse environments.

Through complementary efforts in the West African savannas, researchers at the International Institute of Tropical Agriculture (IITA) have made significant progress in developing early and extra-early maturing maize varieties that can grow in regions with short rainy seasons.

Drought-escaping rice: One of the most exciting advances in crop improvement during recent years has been the development and spread of New Rices for Africa, or NERICA. Resulting from the work of the Africa Rice Center and its national partners, NERICA varieties combine the high productivity of Asian rice with the ability of African rice to tolerate harsh growing conditions. Varieties for rainfed uplands are already being planted on 200,000 hectares and tested in 30 African countries. Farmers are particularly interested in early maturing NERICA varieties, which permit more intensive cropping and tend to escape intermittent droughts occurring at critical stages in crop development.



Waterproof rice: Scientists at the International Rice Research Institute (IRRI) have found a genetic remedy for the risk of flooding in rice crops. In Southeast Asia alone, harvest losses related to flooding have an estimated annual value of US\$1 billion. Rice is the only cereal crop that can withstand any degree of submergence, but most varieties die if fully submerged for more than three days. Now, IRRI researchers

and collaborators have identified a rice gene called *Sub1A*, which allows plants to survive completely submerged for up to two weeks. The “waterproofing” trait has been transferred into a popular rice variety in Bangladesh, and the improved version is giving high yields while protecting harvests against flooding.

The Rice and Climate Change Consortium: Capitalizing on successful results in developing rice tolerant to submergence and soil salinity (another condition expected to worsen as a result of climate change), IRRI has established a research consortium that is addressing the impact of climate change on rice production in all its complexity. Working from the local to global scales, the consortium relies on crop improvement, with the aid of molecular techniques, while also examining the impact of climate change on ecosystem resilience, pest dynamics and other factors.

Enhancing naturally hardy crops: Among the world's most naturally hardy food crops are barley, cassava, millet and sorghum, which are widely grown in dry climates.

Barley breeders at the International Center for Agriculture in the Dry Areas (ICARDA) have demonstrated how drought tolerance in this crop can be markedly improved through a method involving farmer participation. Having first proved successful in Syria, the approach is now being applied in seven other countries of the Middle East and North Africa.

Cassava, a highly productive root crop, performs well even in drought-prone areas and infertile soils. Researchers at IITA are evaluating cassava in semi-arid regions of East and West Africa in an effort to determine what mechanisms enable the crop to withstand dry spells. The results should make it possible to identify genes for this trait and thus further enhance the drought tolerance of cassava, with the aid of new tools from molecular biology.

Using such tools, researchers at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) have isolated and are employing genes for the so-called “stay-green” trait in millet and sorghum. By delaying the death of leaves and plants and enhancing grain development, these genes enhance drought tolerance.

Boosting the yields of grain legumes under drought: CGIAR research on stress tolerance is not limited to the major cereals, but includes grain

legumes as well, since these are critical sources of protein for developing country consumers.

The International Center for Tropical Agriculture (CIAT) has succeeded in breeding drought-tolerant common beans after nearly a quarter century of research. The new beans yield 600 to 750 kilograms per hectare under severe drought, roughly double the maximum yield that Latin American farmers get from commercial varieties under the same conditions. Bean researchers are actively testing the new varieties in Central America and Eastern Africa, while combining their drought tolerance with other traits that farmers need.

Similarly, IITA has incorporated tolerance to drought and heat into cowpea. Some of the tolerant lines have out-yielded susceptible ones by 16 to 142 percent under drought in experimental conditions.

Livestock and Fisheries at Risk

Efforts are also under way to protect animal production from the effects of climate change. As an initial step, researchers at the International Livestock Research Institute (ILRI) are introducing data on the distribution of African livestock breeds into computer-based geographical information systems, or GIS. When overlaid with climate change and ecological data, this information will help select breeds for environments where drought is becoming more prevalent.

In addition, to secure sources of livestock feed, forage researchers at CIAT are selecting and promoting drought-tolerant grass and legume species. An outstanding example is *Cratylia*, a leguminous forage shrub, which shows strong drought tolerance while also improving livestock nutrition.

Meanwhile, experts at the WorldFish Centre are analyzing the potentially overwhelming shock that climate change could cause to fisheries and aquaculture, the main source of animal protein for a billion people worldwide. Higher sea temperatures are already a major cause of damage to coral reefs, which serve as fish breeding habitats. Rising sea levels will also likely damage or destroy wild fish stocks as well as ponds in coastal areas. In addition, changes in inland temperatures and rainfall, together with extreme weather events, could substantially reduce fish stocks. Much further research is needed to better understand the complex impacts of climate change on fisheries and aquaculture and to devise coping strategies.



Shifts in Pest and Disease Pressures

Apart from causing direct damage to crops and animals, higher temperatures and other changes in the global climate may cause them to suffer more from the depredations of diseases and pests. These biotic stresses — including cassava mosaic disease, potato blight, rice blast, wheat stem rust, whiteflies and many others — already take a heavy toll on developing country agriculture. To anticipate and prepare for a worsening of these problems, scientists in various CGIAR Centers are examining the likely effects of climate change on major biotic stresses in agriculture, including certain human and animal diseases, like malaria and trypanosomiasis, which are transmitted by insects.

The International Potato Center (CIP), for example, has already developed a simulation model for potato late blight, the most destructive disease of the crop worldwide. The model can be used with GIS to predict disease severity under the changes in temperature and rainfall that are likely to result from climate change. Equally important are simulation models for forecasting the expected distribution of insects transmitting viruses, such as aphids and whiteflies. Coupled with the CGIAR's large store of knowledge about disease epidemiology, these models will be critical for anticipating the effects of climate change on the spread of dangerous plant viruses worldwide.

Enhancing the Productivity of Water

The CGIAR is supporting a major research effort to improve the productivity of water in agriculture. According to the recently completed Comprehensive Assessment of Water Management in Agriculture, more than a third of earth's population is already affected by water scarcity. Coordinated by the International Water Management Institute (IWMI), the Assessment was a 5-year study that brought together some 700 specialists to examine the impacts of water policies and practices prevailing over the last 50 years.

Climate change will put greater pressure on water resources, as increasingly volatile rainfall

patterns force farmers to rely more heavily on irrigation. But, fortunately, the Comprehensive Assessment points to a wide range of technologies and policy measures that could increase water productivity in both irrigated and rainfed agricultural systems, including those that incorporate livestock and fisheries.

Drip irrigation: Several CGIAR Centers are already actively developing and promoting alternative technologies suitable for small farmers. IWMI, for example, is working with local partners on "bucket and drip" irrigation systems. Water flows from a raised bucket into pipes with emitters scattered throughout the plot, which discharge the water into the soil near the plants by means of a slow-release mechanism. Requiring an investment of only about US\$5, these systems enable growers to apply just enough water to ensure good harvests. While IWMI is concentrating heavily on Southern Africa in this work, ICRISAT researchers are helping introduce drip irrigation in West Africa's Sahel region for the production of high-value vegetables and fruits.

Water harvesting: Arguing against an exclusive focus on irrigation, the Comprehensive Assessment draws attention to the potential for better management of rainwater, even where it is very scarce. Farmers in West Asia and North Africa, for example, inhabiting some of the driest regions on earth, have for hundreds of years practiced "water harvesting." This involves diversion of scarce rainfall from large areas into small parcels containing crops and trees. ICARDA scientists are studying numerous traditional systems for water harvesting, with the aim of helping refine and disseminate them more widely. In Syria, for example, mechanized construction of traditional micro-catchment ridges, using a special plow, has permitted the expansion of water harvesting in degraded rangelands. This has improved the survival rate of shrubs and other plants on which livestock graze.

Collective action to protect a shared resource: In many situations, improved management of water requires not only actions by individual farmers but collective efforts to improve stewardship of this shared resource. Such approaches, requiring the empowerment of local rural institutions, are not easy to replicate on a large scale, but ample evidence from IWMI suggests that this can be done. For example, policy recommendations, generic guidelines and other products resulting

from the Institute's research on "irrigation management transfer" (that is, the transfer of responsibility for management of irrigation to farmer organizations) have had a widespread and profound effect on decision making at the national and global levels.

Similarly, ICRISAT has successfully promoted an integrated approach to watershed management in India and other Asian countries and is now beginning to transfer the innovation to Eastern Africa. An assessment of the impact of this approach in one watershed in India indicated that from 1998 to 2003 the use of new technologies, combined with traditional methods, almost doubled the incomes of small farmers, raised groundwater levels by 5–6 meters, expanded green cover from 129 to 200 hectares and more than doubled agricultural productivity.

Sustainable Soil Management

Boosting water productivity in agriculture is generally inseparable from better management of crops and soil. For that reason, the CGIAR Centers engaged in crop improvement also devote significant effort to soils research, and increasingly this work is integrated with that on water management. Some of the resulting technologies, in addition to helping farmers adapt to harsh growing conditions, contribute to lowering greenhouse gas emissions, for example, by reducing tillage, leaving crop residues in the soil and increasing fertilizer-use efficiency.



A good example of the impact made possible by such work is the rapid spread of "zero-tillage" technology in South Asia's rice-wheat systems. This technology, by reducing mechanized soil tillage and retaining crop residues in the soil, conserves soil and water, while also raising crop productivity. Promoted by a regional consortium with assistance from CIMMYT and IRRI, the technology has also cut farmers' production costs by lowering fuel consumption for tillage. The combination of reduced soil disturbance and increased retention of crop residues results in lower carbon emissions as well. Close to half a million farmers in India, Pakistan and other countries of the region now apply this resource-conserving technology on more than 3.2 million hectares, with economic benefits so far estimated at US\$147 million.

Under quite different circumstances in the West African Sahel, various new practices are better enabling farmers to raise soil fertility, which is essential for making more productive use of scarce rainfall in the region. One of these is a practice called "micro-dosing," in which small quantities of inorganic fertilizers are applied in the hole where a seed is sown. Applying normal doses of fertilizer is too expensive for most farmers in the Sahel and also increases the risk of soil acidification. Promoted by ICRISAT and other CGIAR Centers, micro-dosing has been adopted by thousands of farmers in Burkina Faso, Mali, Niger and Zimbabwe. It helps their crops mature more rapidly and escape the worst effects of drought. Micro-dosing may be combined, to good effect, with other measures, such as mulching with crop residues and the placement of small amounts of mixed organic/inorganic fertilizer in soil mounds formed for planting.

Based on that and many other experiences in Africa and elsewhere, CGIAR-supported networks of tropical soil scientists have devised and are promoting integrated approaches to improving soil fertility that combine targeted application of inorganic nitrogen and phosphorus fertilizers with the use of livestock manure and other locally available organic sources of nutrients.

Quickening the Pace of Change

Fostering the use of technology, knowledge and practices that can enhance the resilience of agricultural systems is a complex challenge for developing countries. But they are making progress and seeing significant impact.

What remains to be seen is whether farming communities can adapt quickly enough to the expected consequences of global climate change and thus forestall major dislocations and greater human suffering in rural areas.

Three conditions must be met to heighten their chances of success: (1) strong market incentives, (2) able institutions and (3) supportive policies that foster positive change. CGIAR researchers are exploring a number of avenues with other international institutions and partners in developing countries to meet those conditions.

Forging market links: To create new incentives for change, rural communities need to be better linked with markets for products and services, including staple foods, horticultural crops, tropical fruits, livestock products, ecotourism and a variety of environmental services. Without such links, the rural poor will be hard pressed to afford the luxury of investing in better management of natural resources.

Partly for that reason, the CGIAR has recently given a more prominent place in its priority setting to research on high-value products. In this work, researchers are giving special emphasis to strengthening the position of small producers in agricultural value chains as a means of combating rural poverty. Value chains encompass the entire sequence of actors involved in adding value to agricultural products — from producers and processors to input suppliers, traders and consumers.

Stronger rural institutions: Stronger rural institutions are required to enable small farmers to derive significant benefits from market links. These are also critical for ensuring that market-driven growth is linked with improved natural resource management. A key function of rural institutions is to offer people opportunities to shape decisions and draw on services that can better enable them to build and maintain sustainable livelihoods.

One such service that could provide small farmers with a new option for managing risk involves innovative weather insurance schemes, linked to micro-credit finance. Improved

availability of climate data, together with better models for predicting weather, have made possible the development of scientifically sound insurance schemes, in which the risks for both farmers and insurers are manageable.

Developing appropriate policies: Enhancing the effectiveness of rural institutions at the local, national and international levels will be a central concern of policy makers, as they seek to speed the pace of agricultural adaptation in the face of global climate change. Scientists at the International Food Policy Research Institute (IFPRI) and other CGIAR Centers are developing information and tools that will provide these people with a stronger basis for analyzing and making sound decisions about difficult tradeoffs between conservation and development.

Among the products that will be available to them are simulation models that permit comprehensive assessments of the many factors affecting food security, poverty and the environment, as influenced by climate change. Such information is critical for defining a vision of the way forward to sustainable development and for designing measures that will help realize that vision.

