Ecological farming: Drought-resistant agriculture

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Contents

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Summary

Human-induced climate change is resulting in less and more erratic rainfall, especially in regions where food security is very low. The poor in rural and dry areas will suffer the most and will require cheap and accessible strategies to adapt to erratic weather. This adaptation will need to take into account not only less water and droughts, but also the increased chance of extreme events like floods.

Biodiversity and a healthy soil are central to ecological approaches to making farming more drought-resistant and more resilient to extreme events. Resilience is the capacity to deal with change and recover after it. Practices that make soils better able to hold soil moisture and reduce erosion and that increase biodiversity in the system help in making farm production and income more resilient and stable.

Building a healthy soil is a crucial element in helping farms cope with drought. There are many proven practices available to farmers right now to help build healthy soils. Cover crops and crop residues that protect soils from wind and water erosion, and legume intercrops, manure and composts that build soil rich in organic matter, enhancing soil structure, are all ways to help increase water infiltration, hold water once it gets there, and make nutrients more accessible to the plant.

In order to feed humanity and secure ecological resilience it is essential to increase productivity in rain-fed areas where poor farmers implement current know-how on water and soil conservation. Ecological farms that work with biodiversity and are knowledge-intensive rather than chemical input-intensive might be the most resilient options under a drier and more erratic climate.

In addition to the ecological farming methods described above, continued breeding of crop varieties that can withstand drought stresses and still produce a reliable yield is needed. Many new drought-tolerant seeds are being developed using advanced conventional breeding, without the need of genetic engineering. There are already examples of drought-resistant soybean, maize, wheat and rice varieties that farmers could start taking advantage of right now. On the other hand, genetic engineering technology is not well suited for developing drought-resistant seeds. Drought tolerance is a complex trait, often involving the interaction of many genes, and thus beyond the capability of a rudimentary technology based on high expression of few well-characterised genes. There is no evidence that genetically engineered (GE) crops can play a role in increasing food security under a changing climate.

1. Adapting to changing rainfall patterns

With a changing climate, farming will need to adapt to changing rainfall patterns. Water is the most crucial element needed for growing food. As we are already seeing, human-induced climate change is resulting in less and more erratic rainfall, especially in regions where food security is very low (IPCC, 2007; Funk et al., 2008; Lobell et al., 2008).

Over 60% of the world's food is produced on rain-fed farms that cover 80% of the world's croplands. In sub-Saharan Africa, for example, where climate variability already limits agricultural production, 95% of food comes from rain-fed farms. In South Asia, where millions of smallholders depend on irrigated agriculture, climate change will drastically affect river-flow and groundwater, the backbone of irrigation and rural economy (Nellemann et al., 2009).

Mexico experienced in 2009 the driest year in seven decades, and this had serious social and economic impacts (Reuters, 2009). It followed a decade-long drought that has already affected the north of the country and the western USA. Further, climate models robustly predict that Mexico will continue to dry as a consequence of global warming (Seager et al., 2009).

Increasing temperatures and less and more erratic rainfall will exacerbate conflicts over water allocation and the already critical state of water availability (Thomas, 2008). The poor in rural and dry areas will suffer the most from these changes and they will require cheap and accessible strategies to adapt to erratic weather.

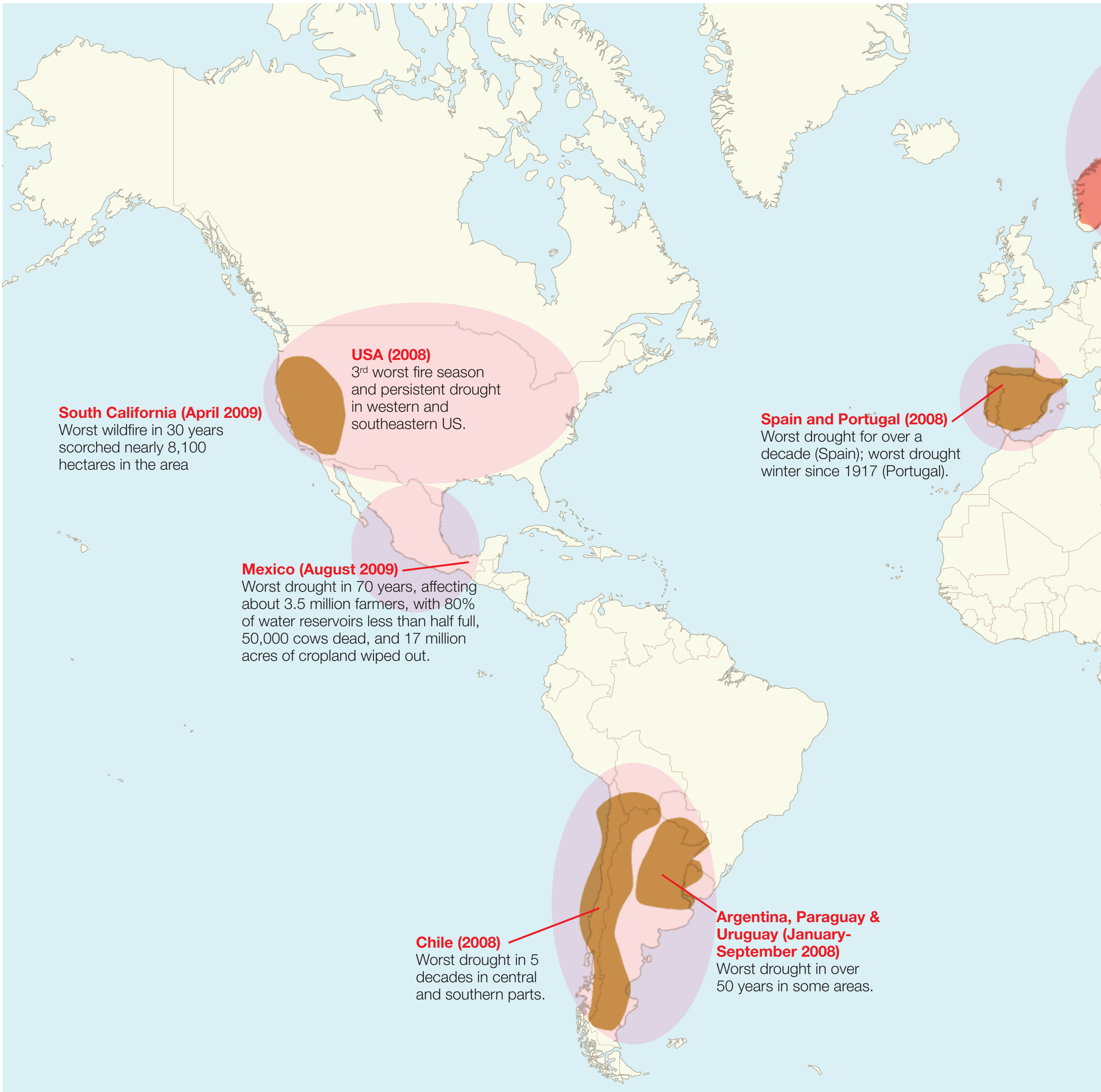
Human-induced drought[1] during the main cropping season in East African countries including Ethiopia, Kenya, Burundi, Tanzania, Malawi, Zambia and Zimbabwe, has already caused rainfall drops of about 15% between 1979 and 2005, accompanied by drastic losses in food production and an increase in food insecurity (Funk et al., 2008). Droughts during the main cropping season in tropical and sub-tropical regions are thought to become more likely in the near future, and will have dangerous effects on human societies (Funk et al., 2008, Lobell et al., 2008). Lobell et al. (2008) calculated a drop in precipitation of up to 10% in South Asia by 2030, accompanied by decreases in rice and wheat yields of about 5%. Funk et al. (2008) predicted potential impacts of up to a 50% increase in undernourished people in East Africa by 2030.

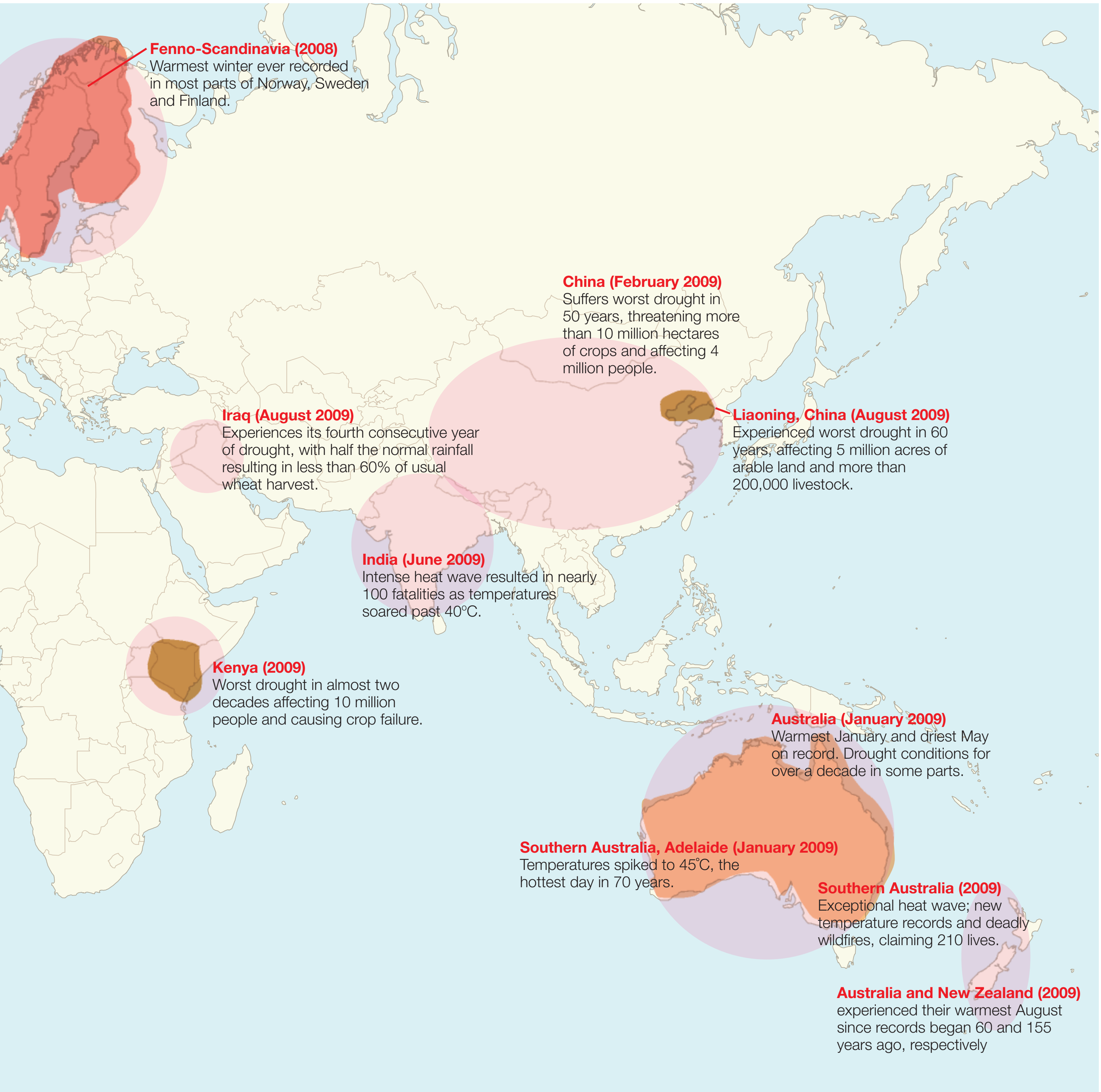
Humans have been tapping natural biodiversity to adapt agriculture to changing conditions since the Neolithic Revolution brought about by the development of farming about 10,000 years ago. Science shows that diversity farming remains the single most important technology for adapting agriculture to a changing climate.

The inherent diversity and complexity of the world's farming systems preclude the focus on a single 'silver bullet' solution. A range of approaches is required for agriculture in a changing climate. In this report, we examine strategies to withstand drought in agriculture using ecological farming based on biodiversity. We also take a look at the successes and assess the potential of conventional breeding methods, including marker assisted selection (MAS), to produce drought-resistant varieties without the environmental and food safety risks associated with genetically-engineered (GE) crops. Finally, we review some of the proposed GE drought-tolerant plant varieties.

1 'Human-induced drought' here refers to drought linked to anthropogenic changes in climatic conditions, such as the late 20th century human-caused Indian Ocean warming linked recently to droughts in East Africa (Funk et al. 2008).

Significant climate anomalies from 2008 / 2009





Adapted from UNEP's Climate Change Science Compendium 2009, available at: http://www.unep.org/compendium2009/

2. Ecological farming is essential to adapt to drought

With water scarcity being the main constraint to plant growth, plants have developed - over millions of years - natural mechanisms to cope with drought. These mechanisms are complex and very diverse, from enhanced root growth to control of water loss in leaves. Often, the breeding of cultivated crops under ideal well-watered conditions results in the loss of those traits that enable coping with little water. In the race to produce larger industrial monocultures fuelled by agrochemicals and massive irrigation, the diversity of plant traits available to cope with little water in industrial cultivated crops has been reduced. However, this diversity is still present in crop varieties and wild relatives. For example, scientists tapping into the diversity of wild relatives of cultivated tomatoes were able to obtain more than 50% higher yields, even under drought conditions (Gur & Zamir, 2004). A detailed analysis on breeding for drought tolerance is given in Chapter 3.

In addition to new breeding, there are numerous ecological farming methods that already help farmers cope with less and more erratic rainfall. In a recent meeting at Stanford University, a group of experts - including crop scientists from seed companies - concluded as part of their recommendations that *"particularly for managing moisture stress in rain-fed systems, agronomy may well offer even greater potential benefits than improved crop varieties"* (Lobell, 2009).

Biodiversity and a healthy soil are central to ecological approaches to making farming more drought-resistant (see below). For example, in sub-Saharan Africa, something as simple as intercropping maize with a legume tree helps soil hold water longer than in maize monocultures (Makumba et al., 2006). Building a resilient food system - one that is able to withstand perturbations and rebuild itself afterwards -works by building farming systems based on biodiversity on multiple scales, from the breeding technology up to the farm landscape.

Farmers around the world need more support from governments and agricultural researchers to move towards resilient ecological farming systems, as recently recognised by the United National Environmental Program (Nellemann et al., 2009). In the sections below, we summarise some of examples of such farming systems from around the world, backed by scientific studies.

2.1. Stability and resilience are key to survival with less and more erratic rainfall

"Two decades of observations reveal resilience to climate disasters to be closely linked to levels of farm biodiversity" (Altieri & Koohafkan 2008)

IPCC[2] climate change models clearly predict more droughts in many regions but at the same time a very likely increased chance of extreme events, such as heavier precipitation, with great implications for crop losses (Bates et al. 2008). Scientists have computed, for example, that "agricultural losses in the US due to heavy precipitation and excess soil moisture could double by 2030" (Rosenzweig & Tubiello, 2007).

Adaptation to changes in average climate conditions - such as an increase in mean air temperature when moving closer towards the equator - usually requires changes in very specific agronomic practices, like new cultivar seeds. In contrast, adaptation to the projected increase in climate variability, such as more floods and more droughts, will require "attention to stability and resilience of crop production, rather than improving its absolute levels" (Rosenzweig & Tubiello, 2007).

Resilience is the capacity to deal with change and recover after it. In many regions, farmers benefit from cropping systems that have evolved to provide stability of production over time, rather than maximising production in a year, and thus providing less risk and more secure incomes under uncertain weather. For example, the practice of leaving fields periodically fallow, resting and accumulating moisture in intervening years, has been shown to give more stability and provide higher yields in the long term because it reduces the risks of crop failure.

Practices that make soils richer in organic matter, more able to hold soil moisture and reduce erosion, and which increase biodiversity in the system all help in making farm production and income more resilient and stable. Cropping rotations, reduced tillage, growing legume cover crops, adding manure and compost and fallow techniques are all proven and available practices to farmers right now. Besides increasing stability and resilience to more droughts and/or floods in the near future, they also contribute to climate change mitigation through sequestration of soil carbon (Rosenzweig & Tubiello, 2007). Scientists now believe that practices that add carbon to the soil, such as the use of legumes as green manure, cover cropping, and the application of manure, are key to the benefits of increasing soil carbon in the practice of soil conservation and reduced tillage (Boddey et al., 2010; De Gryze et al., 2009).

Experts are proposing that in order to feed humanity and secure ecological resilience, a 'green-green-green' revolution[3] is needed, one that is based on increased productivity in rain-fed areas where poor farmers implement current know-how on water and soil conservation (such as growing legumes as cover crops and mulching to increase organic matter and thus soil water-holding capacity) (Falkenmark et al., 2009). A central theme of this revolution would be the better use of green water (i.e., water as rain and soil moisture, as opposed to irrigation blue water from reservoirs or groundwater), to increase the amount of food that can be grown without irrigation. As shown by agricultural trials in Botswana, maize yields can in fact be more than doubled by adopting practices like manure application and reduced tillage (SIWI, 2001).

2 Intergovernmental Panel on Climate Change
3 "Green for production increase, green for being green water based, and green in the sense of environmentally sound" (Falkenmark et al., 2009).

In a recent quantification of global water limitations and crop production under future climate conditions, it has been shown that a combination of harvesting 25% of the run-off water combined with reducing evaporation from soil by 25% could increase global crop production by 20%. This high potential for increase crop production and reducing risk of crop failure in rain-fed areas could come from wide-scale implementation of soil and water conservation techniques, like cover crops, reduce tillage, etc (Rost et al., 2009).

According to scientists at the Stockholm Resilience Centre, putting resilience into practice should start with two crucial building blocks: firstly, finding ways to increase biodiversity in the system (such as implementing some of the multiple ecological farming practices available to rain-fed farmers), and secondly, building knowledge networks and social trust within the system (Quinlin, 2009). Thus, ecological farms that work with biodiversity and which are knowledge-intensive rather than chemical input-intensive might be the most resilient options under a drier, more erratic climate.

Under large perturbations, like heavy rains and hurricanes, ecological farming practices appear to be more resistant to damage and capable of much quicker recovery than conventional farms. For example, ecological agriculture practices such as terrace bunds, cover crops and agro-forestry were found to be more resilient to the impact of Hurricane Mitch in Central America in 1998 (Holt-Gimenez, 2002). Ecological farms with more labour-intensive and knowledge-intensive land management had more topsoil and vegetation, less erosion, and lower economic losses than conventional farms after the impact of this hurricane. Farms with more agroecological practices suffered less from hurricane damage.

In coffee farms in Chiapas, Mexico, farmers were able to reduce their vulnerability to heavy rain damage (e.g., landslides) by increasing farm vegetation complexity (both biodiversity and canopy structure) (Philpott et al., 2008).

2.2. Drought-resistant soils are those rich in organic matter and high in biodiversity

Building a healthy soil is critical in enabling farms to cope with drought. Cover crops and crop residues that protect soils from wind and water erosion, and legume intercrops, manure and composts that build soil rich in organic matter thus enhancing soil structure, are all ways to help increase water infiltration, hold water in the soil, and make nutrients more accessible to the plant.

Healthy soils rich in organic matter, as the ones nurtured by agroecological fertilisers (green manures, compost, animal dung, etc), are less prone to erosion and more able to hold water. A large amount of scientific evidence shows that organic matter is the most important trait in making soils more resistant to drought and able to cope better with less and more erratic rainfall (Bot & Benites, 2005; Lal, 2008; Pan et al., 2009; Riley et al., 2008).

Organic matter increases the pore space in the soil, where water can be held more easily, making the soil capable of storing more water during a longer period and facilitating infiltration during heavy rains so that more water overall can be captured. As a consequence, a soil rich in organic matter needs less water to grow a crop than a soil poor in organic matter. Organic matter also improves the activity of micro-organisms, earthworms and fungi, which makes the soil less dense, less compacted and with gives it better physical properties for storing water (Fließbach et al., 2007; Mäder et al., 2002). All these characteristics make soils rich in organic matter more drought-resistant, increasing the water-use efficiency of not only the crop but the whole farm.

In many regions, crops do not use most of the water they receive because farm soils are unable to store this water (water is lost by run-off, for example). Many ecological farming practices are available that create soils rich in organic matter with better capacity to conserve water in the root zone and increase water-use efficiency. Mulching with crop residues, introducing legumes as cover crops, and intercropping with trees all build soil organic matter, thus reducing water run-off and improving soil fertility. There is a strong need to validate these practices under locally-specific farm conditions and with farmer participation, to facilitate widespread adoption (Lal, 2008).

Crops fertilised with organic methods have been shown to more successfully resist both droughts and torrential rains. During a severe drought year in the long-standing Rodale organic farms in Pennsylvania, USA, the maize and soybean crops fertilised with animal manure showed a higher yield (ranging between 35% to 96% higher) than the chemically-fertilised crop. The higher water-holding capacity in the organically-fertilised soils seems to explain the yield advantage under drought, as soils in organic fields captured and retained more water than in the chemically fertilised fields. Moreover, during torrential rain, organic fields were able to capture about 100% more water than the chemical fields (Lotter et al., 2003).

High soil biodiversity also helps with drought-resistance. Plants are not organisms that can be considered independently from the medium in which they grow. In fact, the vast majority of plants in nature are thought to be associated with some kind of fungi in the soil. Many fungi associated with plants (both mycorrhizal and endophytic species) increase plant resistance to drought and plant water uptake (Marquez et al., 2007; Rodriguez et al., 2004).

These stress-tolerance associations between plants and fungi are only now beginning to be understood, and scientists believe that there is great potential for the use of these natural associations in the mitigation and adaptation to climate change (Rodriguez et al., 2004). For example, tomato and pepper plants living in association with some soil fungi species are able to survive desiccation for between 24 and 48 hours longer than plants living without fungi (Rodriguez et al., 2004). As soils managed with ecological farming practices are richer in microbes and fungal species, they create the conditions for plants to establish these essential drought-tolerance associations.

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Dry canal in Karimnagar, Andhra Pradesh, where the failing monsoons of 2009 left farmers struggling with drought. Water-demanding crops, including rice and cotton failed as a result.

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Farmer burning his rice field after harvest. This practice, now widespread in India, contributes to emissions of greenhouse gases from agriculture. It also reduces the input of organic matter into the soil, which is much needed for improving farm soil health.

BOX 1: Soil degradation in Punjab (India) endangers food production under climate change

According to a review by the Food and Agricultural Organisation (FAO) in the 1990s, about half of the cultivable soils in India were degraded, and the situation has not improved. Since World War II, soil degradation in Asia had led to a cumulative loss of productivity in cropland of 12.8% (Oldeman, 1998).

Soil degradation, mainly the decline both in quality and quantity of soil organic matter, is one of the major reasons linked to stagnation and decline in yields in the most intensive agriculture areas in India, such as Punjab (Dawe et al., 2003; Yadav et al., 2000; Ladha et al., 2003). The decline in soil organic matter is related to the improper use of synthetic fertilisers and lack of organic fertilisation, practices that are now widespread in the most intensive agriculture areas in India (Masto et al., 2008; Singh et al., 2005).

Over-application of nitrogen fertilisers (usually only urea), common in Punjabi farms and influenced by the government's subsidy system on nitrogen, is not only causing nutrient imbalances, but also negatively affecting the physical and biological properties of the soils. For example, indicators of good soil fertility like microbial biomass, enzymatic activity and water-holding capacity are all drastically reduced under common nitrogen fertiliser practices (Masto et al., 2008).

Burning rice straw after harvest, now a widespread practice in many places of the Indo Gangetic Plains of India, is also causing large losses of major nutrients and micronutrients, as well as organic matter (Muhammed, 2007).

Another common detrimental effect of the excessive use of nitrogen fertiliser on soil health is acidification, and the impact it has on soil living organisms, crucial also for natural nutrient cycling and water-holding capacity (Darilek et al., 2009; Kibblewhite et al., 2008).

Many Indian scientists are calling for a revision of the current unsustainable farming practices that provoke soil degradation and are compromising the future of the country's food security, especially under a drier and more unstable climate (Gupta & Seth, 2007; Mandal et al., 2007; Masto et al., 2008; Prasad, 2006; Ranganathan et al., 2008).

2.3. Biodiversity increases resilience from seed to farm scales

There is abundant scientific evidence showing that crop biodiversity has an important role to play in adaptation to a changing environment. While oversimplified farming systems, such as monocultures of genetically identical plants, would not be able to cope with a changing climate, increasing the biodiversity of an agroecosystem can help maintain its long-term productivity and contribute significantly to food security.

Genetic or species diversity within a field provides a buffer against losses caused by environmental change, pests and diseases. Biodiversity (on a seed-to-farm scale) provides the resilience needed for a reliable and stable long-term food production (Diaz et al., 2006).

Under present and future scenarios of a changing climate, farmers' reliance on crop diversity is particularly important in drought-prone areas where irrigation is not available. Diversity allows the agroecosystem to remain productive over a wider range of conditions, conferring potential resistance to drought (Naeem et al., 1994).

In the dry-hot habitats of the Middle East, some wild wheat cultivars have an extraordinary capacity to survive drought and make highly efficient use of water, performing especially well under fluctuating climates (Peleg et al., 2009). Researching the diversity and drought-coping traits of wild cultivars provides scientists with new tools to breed crops better adapted to less rainfall.

In Italy, a high level of genetic diversity within wheat fields on non-irrigated farms reduces the risk of crop failure during dry conditions. In a modelling scenario, where rainfall declines by 20%, the wheat yield would fall sharply, but when diversity is increased by 2% not only is this decline reversed, above average yields can also achieved (Di Falco & Chavas, 2006; 2008).

In semi-arid Ethiopia, growing a mix of maize cultivars in the same field acts like an insurance against dry years. Fields with mixed maize cultivars yielded about 30% more than pure stands under normal rainfall years, but outperformed with 60% more yield than monocultures in dry years (Tilahun, 1995).

In Malawi, sub-Saharan Africa, intercropping maize with the legume tree, gliricidia, has been shown in long-term studies to improve soil nutrients and fertility, providing inexpensive organic fertiliser for resource-poor farmers. In addition, fields with intercropped maize and gliricidia trees hold about 50% more water two weeks after a rain than soil in fields with maize monoculture (Makumba et al., 2006). This is an example of the combined benefits of more biodiversity and healthier soils for coping with less water, in addition to being an example of farm-level cropping diversity.

In a recent analysis of the longest-running biodiversity experiment to date in Minnesota, USA, researchers have shown that maintaining multiple ecosystem functions over years (for example, high productivity and high soil carbon) requires both higher richness of species within a plot and also diversity of species assemblages across the landscape (Zavaleta et al., 2010).

3. Breeding new varieties for use in ecological farming systems

In addition to the ecological farming methods detailed above, continued breeding of crop varieties that can withstand drought stresses and still produce a reliable yield is needed. There are several methods currently being used to develop drought-tolerant crops: conventional breeding, conventional breeding utilising marker-assisted selection (MAS) and genetic engineering.

BOX 2: Marker-assisted selection (MAS) or breeding (MAB) utilises knowledge of genes and DNA, but does not result in a genetically engineered organism. In MAS, specific DNA fragments (markers) are identified, which are closely linked to either single genes or to quantitative trait loci (QTLs). QTLs are a complex of genes that are located close together in the plant genome. Together, these genes contribute to a quantitative trait, like drought tolerance or root architecture. Markers are used with MAS to track certain QTLs during conventional breeding. After crossing, the offspring are screened for the presence of the marker, and hence the desired trait(s). This process eliminates the time-consuming step of growing the plant under stress conditions (e.g. drought) in order to identify plants with the desired trait, which would be the case with conventional breeding. Thus, MAS is often viewed as 'speeded up' or 'smart' conventional breeding. One important advantage of MAS over traditional breeding is that 'linkage drag' - where unwanted traits are introduced along with desired traits - can be avoided. While MAS uses genetic markers to identify desired traits, no gene is artificially transferred from one organism into another one. However, increased public investment is required to avoid patent claims on new crop varieties, including those developed by MAS.

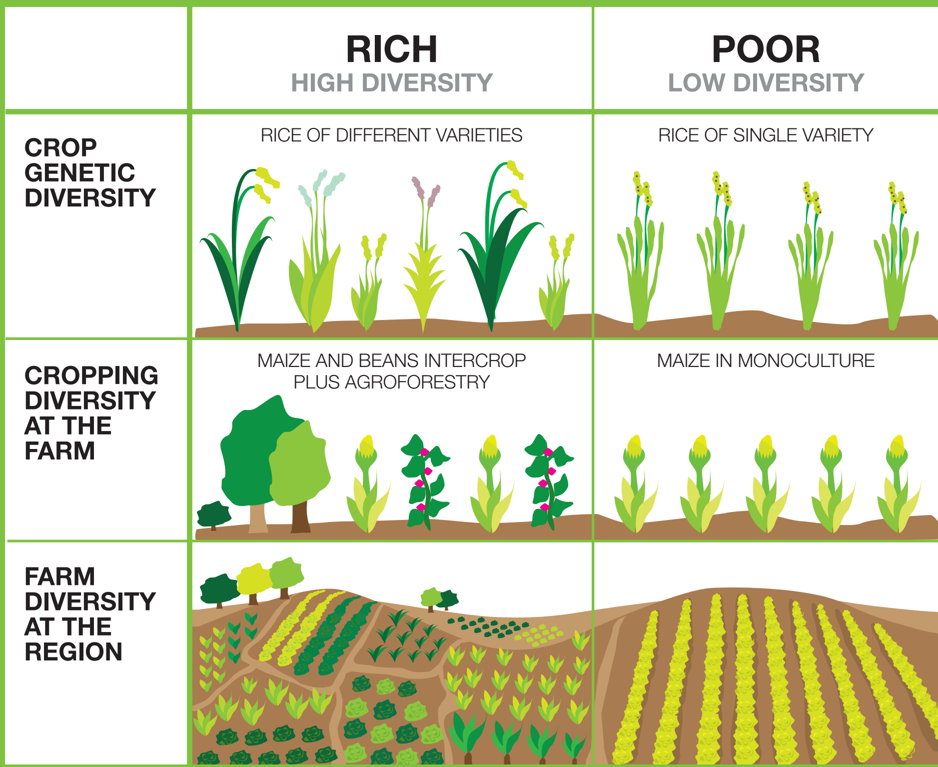
Drought-resistance is thought to be controlled by several to many genes, often likely acting in an orchestrated fashion. This makes it a complex trait. Because of this complexity, breeding drought-tolerant varieties is extremely difficult (Reynolds & Tuberosa, 2008; Anami et al., 2009). This holds true not only for conventional breeding approaches, but also for MAS (Francia et al., 2005) and genetic engineering (Passioura, 2006). Marker-assisted selection is an extremely useful technique for breeding complex traits, such as drought tolerance, into new varieties. It allows many genes (which may act together in the plant genome) to be transferred in one breeding cycle, meaning that seed development and breeding programmes progress more rapidly than traditional conventional breeding.

BOX 3: Different levels of biodiversity on the farm

Crop genetic diversity is the richness of different genes within a crop species. This term includes diversity that can be found among the different varieties of the same crop plant (such as the thousands of traditional rice varieties in India), as well as the genetic variation found within a single crop field (potentially very high within a traditional variety, very low in a genetically engineered or hybrid rice field).

Cropping diversity at the farm level is the equivalent to the natural species richness within a prairie, for example. Richness arises from planting different crops at the same time (intercropping a legume with maize, for example), or from having trees and hedges on the farm (agroforestry). Farm-level cropping diversity can also include diversity created over time, such as with the use of crop rotations that ensure the same crop is not grown constantly in the same field.

Farm diversity at the regional level is the richness at landscape level, arising from diversified farms within a region. It is high when farmers in a region grow different crops in small farms as opposed to large farms growing the same cash crop (for example, large soya monocultures in Argentina).



The starting point for breeding programmes is also important. For example, some varieties of wheat developed during the Green Revolution have only short roots – decreasing their capacity for drought tolerance (Finkel, 2009). Breeding stock could come from historical or traditional drought-resistant varieties, making use of the large seed repositories held across the globe by the Consultative Group on International Agricultural Research (CGIAR) centres (e.g., the International Maize and Wheat Improvement Center (Centro Internacional de Mejoramiento de Maíz y Trigo - CIMMYT), International Rice Research Institute (IRRI)).

Both conventional breeding and MAS have already made an impact on the development of drought-tolerant crop varieties, for example through specific CIMMYT programmes for drought-tolerant maize, but yet their full potential has not yet been utilised (Stevens, 2008; Anami et al., 2009). Conversely, there is much scepticism that a panacea can be delivered in the form of a single 'drought tolerance' gene that has been genetically engineered into a plant.

Many drought-related markers (QTLs) have been mapped in a large number of crops, including rice, maize, barley, wheat, sorghum and cotton (Bernardo, 2008; Cattivelli et al., 2008) and much of the information on these QTL findings has been collected in open source databases.[4] The entire genomic sequence of rice is in the public domain, and this has aided the identification of QTLs (Jena & Mackill, 2008). The maize genome was made public at the end of 2009, which will similarly greatly aid identification of QTLs in maize (Schnable et al., 2009).

MAS is now assisting in the breeding of drought-resistant varieties of several crops (Tuberosa et al., 2007). Most drought-tolerant QTLs detected in the past had a limited utility for applied breeding, partially due to the prevalence of genetic background and environmental effects. However, the recent identification of QTLs with large effects for yield under drought is expected to greatly increase progress towards MAS drought-tolerant crops (Reynolds & Tuberosa, 2008; Bernardo, 2008; Cattivelli et al., 2008; Collins et al., 2008).

Conventionally bred drought-tolerant crops are already available (developed both with and without MAS). For example, the US Department of Agriculture (USDA) has already released a drought-resistant soybean developed using MAS.[5] Following are examples of commercially available conventionally bred (with or without MAS) drought-tolerant maize, wheat and rice crops.

• Maize
The conventionally-bred maize variety ZM521 was developed by CIMMYT. To develop the new variety, scientists from CIMMYT drew on thousands of native varieties of corn from seed banks, which were built up through decades of free exchange of landraces around the globe (Charles, 2001). By repeated cycles of inbreeding and selection, the scientists uncovered the previously hidden genetic traits that enable maize to withstand drought. ZM521 is a maize variety that not only exhibits remarkable vigour when afflicted by water shortage, but also yields 30% to 50% more than traditional varieties under drought (CIMMYT, 2001). Another of the pro-poor advantages of ZM521 is that it is open-pollinated. In contrast to hybrid and GE maize varieties, seeds from open-pollinated forms can be saved and planted the following year. This benefits smallholder farmers who often face cash constraints when buying new seed. ZM521 seeds are now available free of charge to seed distributors around the world and in several African countries, including South Africa and Zimbabwe, ZM521 has been released for cultivation on farmers' fields.
(Extracted from Vogel, 2009)

• Wheat
The wheat varieties Drysdale and Rees are two further notable examples showing that conventional breeding can be used to develop drought tolerance. Using conventional breeding techniques, wheat breeding scientists from Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) succeeded in increasing water-use efficiency, an important drought-tolerance strategy. Drysdale, for example, can outperform other varieties by between 10% and 20% (Finkel, 2009) in arid conditions and up to 40% under very dry conditions (Richards, 2006). DNA markers that track genes conferring drought tolerance are now being used to improve Drysdale and a new variety developed by this MAS approach is expected to be ready by 2010 (Finkel, 2009). In addition, the CSIRO techniques are now being used to breed drought-tolerant maize in sub-Saharan Africa (Finkel, 2009).
(Extracted from Vogel, 2009)

• Rice
In 2007, MAS 946-1 became the first drought-tolerant aerobic rice variety released in India. To develop the new variety, scientists at the University of Agricultural Sciences (UAS), Bangalore, crossed a deep-rooted upland japonica rice variety from the Philippines with a high yielding indica variety. Bred with MAS, the new variety consumes up to 60% less water than traditional varieties. In addition, MAS 946-1 gives yields comparable with conventional varieties (Gandhi, 2007). The new variety is the product of five years of research by a team lead by Shailaja Hittalmani at UAS, with funding from the IRRI and the Rockefeller Foundation (Gandhi, 2007).

In 2009, IRRI recommended two new drought-tolerant rice lines for release, which are as high yielding as normal varieties: IR4371-70-1-1 (Sahbhagi dhan) in India and a sister line, IR4371-54-1-1 for the Philippines (Reyes, 2009a). Field trials in India are being reported as very successful, with the rice tolerating a dry spell of 12 days (BBC, 2009). Similarly, drought-resistant rice suitable for cultivation in Africa is being developed using MAS by IRRI, in conjunction with other research institutes (Mohapatra, 2009). IRRI scientists are also researching genetic engineering approaches to drought-tolerant rice but these are in the early stages of development, with 'a few promising lines' that need 'further testing and validation' (Reyes, 2009b). In contrast, the MAS drought-resistant rice is already being released to farmers.
(Extracted from Vogel, 2009)

4 See for example http://wheat.pw.usda.gov/GG2/index.shtml
5 http://www.wisconsinagconnection.com/story-national.php?Id=808&yr=2009

"In Eastern India drought affects rice farmers very significantly. In dry years, like 2009, about 60% of the rice area remained uncultivated due to lack of water. Farmers see how water availability is reducing year after year. Sahabhagi dhan, the rice seeds we have been working on with farmers for a few years, can be seeded directly in farm fields, even in dry years when rains come late and scarcely. The benefits of Sahabhagi dhan are also related to its short duration, which allow farmers to plant a second crop of legumes (chick pea, lentil, etc), rapeseed or linseed. Rice seeds better able to resist drought plus an additional crop would not only contribute to better farm income, but would also motivate farmers to stay back in the farm in winter months instead of having to migrate to towns for non-farm employment."
Dr. Mukund Variar, Principal Scientist and Officer-in-Charge of Central Rainfed Upland Rice Research Station, Indian Council of Agriculture Research (ICAR) centre where the drought-resistant rice, Sahabhagi dhan, was developed in Jharkhand (India).

3.1. Genetic engineering is not a suitable technology for developing new varieties of drought-resistant crops

"To think gene transfer replaces conventional breeding for drought is unrealistic. We don't yet understand the gene interactions well enough.,"
Matthew Reynolds of CIMMYT, Mexico (Finkel, 2009)

"There is at present little evidence that characteristics enabling survival under the drastic water stresses typically imposed on the tested transgenic lines will provide any yield advantage under the milder stress conditions usually experienced in commercially productive fields. In contrast, exploitation of natural variation for drought-related traits has resulted in slow but unequivocal progress in crop performance." (Collins et al., 2008)

There have been several attempts to create drought-tolerant GE crops, in both the private and public sectors, although the private sector dominates. Government scientists in Australia are reported to have field-trialed experimental GE drought-resistant wheat.[6] The largely publicly-funded IRRI is researching GE approaches to achieve drought-tolerant rice (detailed above), although IRRI-developed MAS drought-resistant rice is already being released to farmers. The biotechnology companies Monsanto and BASF are aggressively promoting their GE drought-tolerant maize, which uses bacterial genes. They have applied to US[7] and Canadian[8] regulatory authorities for commercialisation of this GE maize (in the US, commercialisation is actually a decision to give the crop non-regulated status) and also to other countries, including Australia and New Zealand,[9] for imports of the GE maize in food.

Genetic engineering can be used to insert genes into a plant, but controlling the inserted genes presents more of a problem. Mostly, the genes are active in all a plant's cells, during all stages of a plant's life. Commercial GE crops predominantly only involve simple traits (herbicide tolerance and insect resistance traits) that only involve single genes. The insertion of many genes (as would be required for expression of a multi-gene trait) is possible through genetic engineering but much more difficult is making all the genes operate together (Bhatnagar-Mathur et al., 2008). Therefore, genetic engineering approaches to traits such as drought tolerance tend to only involve a single primary gene that is highly (or over-) expressed. This is exactly the case with Monsanto's GE drought-tolerant maize: a single primary gene (for cold tolerance) is inserted and under the control of a switch (35S promoter) that turns the gene on in every cell, all the time (Castiglioni et al., 2008).

The GE drought-tolerant maize contains a gene from a bacterium that produces a 'cold shock protein', which aids the bacterium to withstand sudden cold stress (Castigioni et al., 2008). Coincidentally, Monsanto discovered that the proteins produced by these genes also aid plants, including maize, to tolerate stresses such as drought. However, the fundamental science of how this particular protein helps the plant resist drought stress is far from understood. It is thought that the protein helps enable the folding of important molecules (RNA) in the cell nucleus into the structure required by the cell. However, exactly *which* molecule this particular protein helps fold is not known. Nor is it known exactly how this protein helps the plant withstand drought. This new GE maize does not seem to use water more efficiently, nor does it help build a more resilient soil or crop. It merely makes the maize plant tolerate drought stress using a bacterial mechanism, with unknown consequences for plant ecophysiology under field conditions.

BOX 4:

For maize, there is a programme entitled 'Water-Efficient Maize for Africa (WEMA)', which involves several partners, including BASF and Monsanto, to develop drought-tolerant maize for Africa. This project utilises both MAS and genetic engineering approaches. One website for the project[10] says that "*The first conventional varieties developed by WEMA could be available after six to seven years of research and development. The transgenic drought-tolerant maize hybrids will be available in about ten years.*" Hence, it appears that conventional breeding using MAS will be available first, providing incontrovertible evidence that such objectives can be met without recourse to risky genetic engineering.

6 http://www.reuters.com/article/pressRelease/idUS189618+17-Jun-2008+BW20080617
7 http://www.aphis.usda.gov/brs/not_reg.html
8 http://www.inspection.gc.ca/english/plaveg/bio/subs/2009/20090324e.shtml
9 http://www.foodstandards.gov.au/_srcfiles/A1029%20GM%20Corn%20AAR%20FINAL.pdf
10 http://www.foodstandards.gov.au/_srcfiles/A1029%20GM%20Corn%20AAR%20FINAL.pdf

BOX 5:

The environmental and food safety of GE crops is unknown, even for those GE varieties where it is understood how the inserted genes act (at least in theory). This lack of understanding is because the inserted genes may disrupt the plant's own genes, be unstable in their new environment, or function differently than expected (Schubert, 2003, Latham et al., 2006). These concerns are heightened with Monsanto's drought-resistant GE maize because it is not known how the protein produced by the inserted gene operates. There is a high probability of unintended interferences with the plant's own RNA because the inserted gene relies on intervention at the RNA level. The consequences may not be identified in any short-term testing undertaken to satisfy regulatory requirements in order to commercialise the crop, or may only be apparent under stress. In addition, there may be unexpected effects on wildlife if this GE crop alters plant metabolism to become either toxic or have altered nutritional properties. These heightened risks for stress-tolerant GE crops pose new problems for regulators (Nickson, 2008; Wilkinson & Tepfer, 2009).

Genetic engineering results in unexpected and unpredictable effects. This is a result of the process of inserting DNA into the plant genome, often at random. By contrast, MAS utilises conventional breeding so that the desired genes that are bred into the plant are under the control of the genome. Thus, the potential for unexpected and unpredictable effects are much less with MAS and the environmental and food safety concerns are much less.

Conclusions

Biodiverse farming and building of healthy soils are proven, effective strategies to adapt to the increase in droughts predicted under climate change. With biodiversity and by nurturing farm soils we can create resilient farms that are able to maintain and increase food production in the face of increasingly unpredictable conditions. Scientifically-proven practices that protect soils from wind and water erosion (e.g., planting cover crops and incorporating crop residues), and which build soil rich in organic matter (e.g., legume intercropping, cover cropping, and adding manure and composts) are all ways to help increase water infiltration, hold water in the soil, and make nutrients more accessible to the plant.

In contrast, genetic engineering has inherent shortcomings pertaining to plant-environment interactions and complex gene regulations that make it unlikely to address climate change either reliably or in the long term. This conclusion is also reflected in the recent IAASTD (2009) report, which considered GE crops to be irrelevant to achieving the Millennium Development Goals and to eradicating hunger. A one-sided focus on GE plants contradicts all scientific findings on climate change adaptation in agriculture, and is a long-term threat to global food security.

Agriculture will not only be negatively affected by climate change, it is a substantial contributor to greenhouse gas emissions. However, by reducing agriculture's greenhouse gas emissions and by using farming techniques that increase soil carbon, farming itself can contribute to mitigating climate change (Smith et al.,2007). In fact, many biodiverse farming practices discussed above are both mitigation and adaptation strategies, as they increase soil carbon and use cropping systems that are more resilient to extreme weather.

To take advantage of the mitigation and adaptation potential of ecological farming practices, governments and policy makers must increase research and investment funding available for ecological farming methods.

References

Altieri MA & Koohafkan P, 2008. Enduring farms: climate change, smallholders and traditional farming communities. Penang, Malaysia: Third World Network.

Anami S, de Block M, Machuka J & Van Lijsebettens M, 2009. Molecular improvement of tropical maize for drought stress tolerance in Sub-Saharan Africa. Critical Reviews in Plant Sciences 28 16-35.

BBC, 2009. India's 'drought-resistant rice'. 5 August
http://news.bbc.co.uk/1/hi/8182840.stm

Bates BC, Kundzewicz ZW, Wu S & Palutikof JP (eds.), 2008. Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

Bhatnagar-Mathur P, Vadez V & Sharma KK, 2008. Transgenic approaches for abiotic stress tolerance in plants: retrospect and prospects. Plant Cell Reports 27: 411-24.

Bernier J, Kumar A, Serraj R, Spaner D & Atlin G, 2008. Review: breeding upland rice for drought resistance. Journal of the Science of Food and Agriculture 88: 927 – 939.

Bernardo R, 2008. Molecular markers and selection for complex traits in plants: Learning from the last 20 years. Crop Science 48: 1649 – 1164.

Boddey RM, Jantalia CP, Conceição PC, Zanatta JA, Bayer C, Mielniczuk J, Dieckow J, Santos HPD, Denardin JE, Aita C, Giacomini SJ, Alves BJR & Urquiaga S, 2010. Carbon accumulation at depth in Ferralsols under zero-till subtropical agriculture. Global Change Biology 16: 784-795.

Bot A & Benites J, 2005. Drought-resistant soils. Optimization of soil moisture for sustainable plant production. Food and Agriculture Organization of the United Nations. Land and Water Development Division.

Castiglioni P, Warner D, Bensen RJ, Anstrom DC, Harrison J, Stoecker M, Abad M, Kumar G, Salvador S & D'Ordine R, 2008. Bacterial RNA chaperones confer abiotic stress tolerance in plants and improved grain yield in maize under water-limited conditions. Plant Physiology 147: 446–455.

Cattivelli L, Rizza F, Badeck F-W, Mazzucotelli E, Mastrangelo AM, Francia E, Marè C, Tondelli A & Stanca AM, 2008. Drought tolerance improvement in crop plants: An integrated view from breeding to genomics. Field Crops Research 105: 1–14.

Charles D, 2001. Seeds of discontent. Science 294: 772 – 775.

Collins NC, Tardieu F & Tuberosa R, 2008. Quantitative trait loci and crop performance under abiotic stress: where do we stand? Plant Physiology 147: 469–486.

CIMMYT, 2001. New maize offers better livelihoods for poor farmers.
www.cimmyt.org/Research/Maize/map/developing_world/nmaize/new_maize.htm (verified 20 March 2009).

Dawe D, Dobermann A, Ladha JK, Yadav RL, Bao L, Gupta RK, Lal P, Panaullah G, Sariam O, Singh Y, Swarup A & Zhen QX, 2003. Do organic amendments improve yield trends and profitability in intensive rice systems? Field Crops Research 83: 191-213.

Darilek JL, Huang B, Wang Z, Qi Y, Zhao Y, Sun W, Gu Z & Shi X. 2009. Changes in soil fertility parameters and the environmental effects in a rapidly developing region of China. Agriculture, Ecosystems & Environment 129: 286-292.

De Gryze S, Albarracin MV, Català-Luque R, Howitt RE & Six J, 2009. Modelling shows that alternative soil management can decrease greenhouse gases. California Agriculture 63: 84-90.

Diaz S, Fargione J, Chapin FS & Tilman D, 2006. Biodiversity loss threatens human well-being. PLoS Biology 4: e277.

Di Falco S & Chavas J-P, 2006. Crop genetic diversity, farm productivity and the management of environmental risk in rainfed agriculture. European Review of Agricultural Economics 33: 289-314.

Di Falco S & Chavas J-P, 2008. Rainfall shocks, resilience, and the effects of crop biodiversity on agroecosystem productivity. Land Economics 84: 83-96.

Falkenmark M, Rockström J & Karlberg L, 2009. Present and future water requirements for feeding humanity. Food Security 1: 59-69.

Finkel E, 2009. Making every drop count in the buildup to a blue revolution. Science 323: 1004-1005. News Focus.

Fließbach A, Oberholzer H-R, Gunst L & Mader P, 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agriculture, Ecosystems & Environment 118: 273-284.

Francia E, Tacconi G, Crosatti C, Barabaschi D, Bulgarelli D, Dall'Aglio E & Vale G, 2005. Marker assisted selection in crop plants. Plant Cell, Tissue and Organ Culture 82: 317–342.

Funk C, Dettinger MD, Michaelsen JC, Verdin JP, Brown ME, Barlow M & Hoell A, 2008. Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. Proceedings of the National Academy of Sciences 105: 11081-11086.

Gandhi D, 2007. UAS scientist develops first drought tolerant rice. The Hindu. www.thehindu.com/2007/11/17/stories/2007111752560500.htm (verified 20 March 2009).

Gur A & Zamir D, 2004. Unused natural variation can lift yield barriers in plant breeding. PLoS Biology 2: e245.

Gupta R & Seth A, 2007. A review of resource conserving technologies for sustainable management of the rice-wheat cropping systems of the Indo-Gangetic plains (IGP). Crop Protection 26: 436-447.

Holt-Gimenez E, 2002. Measuring farmers' agroecological resistance after Hurricane Mitch in Nicaragua: a case study in participatory, sustainable land management impact monitoring. Agriculture, Ecosystems & Environment 93: 87-105.

IAASTD, 2009. International Assessment of Agricultural Science and Technology for Development. Island Press. www.agassessment.org.

IPCC, 2007. Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden & C.E. Hanson, (eds.), Cambridge University Press, Cambridge, UK, 7-22.

Kibblewhite MG, Ritz K & Swift MJ, 2008. Soil health in agricultural systems. Philosophical Transactions of the Royal Society B: Biological Sciences 363: 685-701.

Ladha JK, Dawe D, Pathak H, Padre AT, Yadav RL, Singh B, Singh Y, Singh Y, Singh P, Kundu AL, Sakal R, Ram N, Regmi AP, Gami SK, Bhandari AL, Amin R, Yadav CR, Bhattarai EM, Das S, Aggarwal HP, Gupta RK & Hobbs PR, 2003. How extensive are yield declines in long-term rice-wheat experiments in Asia? Field Crops Research 81: 159-180.

Latham JR, Wilson A & Steinbrecher RA, 2006. The mutational consequences of plant transformation. Journal of Biomedicine and Biotechnology 2006: 1–7.

Jena KK & MacKill DJ, 2008. Molecular markers and their use in marker-assisted selection in rice. Crop Science 48: 1266 – 1276.

Lal R, 2008. Managing soil water to improve rainfed agriculture in India. Journal of Sustainable Agriculture 32: 51-75.

Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP & Naylor RL, 2008. Prioritizing climate change adaptation needs for food security in 2030. Science 319: 607-610.

Lobell DB, 2009. Climate Extremes and Crop Adaptation. Summary statement from a meeting at the program on Food Security and Environment, Stanford, CA, held on June 16-18, 2009.
http://foodsecurity.stanford.edu/publications/climate_extremes_and_crop_adaptation/.

Lotter DW, Seidel R & Liebhardt W, 2003. The performance of organic and conventional cropping systems in an extreme climate year. American Journal of Alternative Agriculture 18: 146-154.

Mäder P, Fließbach A, Dubois D, Gunst L, Fried P & Niggli U, 2002. Soil fertility and biodiversity in organic farming. Science 296: 1694-1697.

Makumba W, Janssen B, Oenema O, Akinnifesi FK, Mweta D & Kwesiga F, 2006. The long-term effects of a gliricidia-maize intercropping system in Southern Malawi, on gliricidia and maize yields, and soil properties. Agriculture, Ecosystems & Environment 116: 85-92.

Mandal B, Majumder B, Bandyopadhyay PK, Hazra GC, Gangopadhyay A, Samantaray RN, Mishra AK, Chaudhury J, Saha MN & Kundu S, 2007. The potential of cropping systems and soil amendments for carbon sequestration in soils under long-term experiments in subtropical India. Global Change Biology 13: 357-369.

Marquez LM, Redman RS, Rodriguez RJ & Roossinck MJ, 2007. A virus in a fungus in a plant: three-way symbiosis required for thermal tolerance. Science 315: 513-515.

Masto R, Chhonkar P, Singh D & Patra A, 2008. Alternative soil quality indices for evaluating the effect of intensive cropping, fertilisation and manuring for 31 years in the semi-arid soils of India. Environmental Monitoring and Assessment 136: 419-435.

Mohapatra S, 2009. Drought-proof rice for African farmers. Rice Today 8: 41-42 http://beta.irri.org/news/index.php/200904056045/Rice-Today/Africa/Drought-proof-rice-for-African-farmers.html

Muhammed SE, 2007. Modeling long-term dynamics of carbon and nitrogen in intensive rice-based cropping systems in the Indo-Gangetic Plains (India). . PhD thesis, Wageningen University, Wageningen, The Netherlands. http://library.wur.nl/wda/dissertations/dis4207.pdf.

Naeem S, Thompson LJ, Lawler SP, Lawton JH & Woodfin RM, 1994. Declining biodiversity can alter the performance of ecosystems. Nature 368: 734-737.

Nickson TE, 2008. Planning environmental risk assessment for genetically modified crops: problem formulation for stress-tolerant crops. Plant Physiology 147: 494-502.

Nellemann C, MacDevette M, Manders T, Eickhout B, Svihus B, Prins AG & Kaltenborn BP, 2009. The environmental food crisis – The environment's role in averting future food crises. A UNEP rapid response assessment. United Nations Environment Programme, GRID-Arendal, www.grida.no.

Oldeman LR, 1998. Soil degradation: a threat to food security? Report 98/01, International Soil Reference and Information Centre, Wageningen.

Pan G, Smith P & Pan W, 2009. The role of soil organic matter in maintaining the productivity and yield stability of cereals in China. Agriculture, Ecosystems & Environment 129: 344-348.

Passioura J, 2006. Increasing crop productivity when water is scarce— from breeding to field management. Agricultural Water Management 80: 176-196.

Peleg Z, Fahima T, Krugman T, Abbo S, Yakir D, Korol AB & Saranga Y, 2009. Genomic dissection of drought resistance in durum wheat x wild emmer wheat recombinant inbreed line population. Plant, Cell & Environment 32: 758-779.

Philpott SM, Lin BB, Jha S & Brines SJ, 2008. A multi-scale assessment of hurricane impacts on agricultural landscapes based on land use and topographic features. Agriculture, Ecosystems & Environment 128: 12-20.

Prasad VK & Badarinath KVS, 2006. Soil surface nitrogen losses from agriculture in India: A regional inventory within agroecological zones (2000-2001). International Journal Of Sustainable Development And World Ecology 13: 173-182.

Quinlin A, 2009. How is resilience put into practice? Stockholm Resilience Centre. http://www.stockholmresilience.org/research/whatisresilience/resiliencevideoschool/howisresilienceputintopractise.4.aeea46911a31274279800013889.html

Ranganathan J, Daniels RJR, Chandran MDS, Ehrlich PR & Daily GC, 2008. Sustaining biodiversity in ancient tropical countryside. Proceedings of the National Academy of Sciences 105: 17852-17854.

Reuters, 2009. Noel Randewich. Mexico hit by lowest rainfall in 68 years http://www.reuters.com/article/worldNews/idUSTRE57I5KE20090819?pageNumber=2&virtualBrandChannel=0&sp=true

Reyes LC, 2009a. Making rice less thirsty. Rice Today 8: 12-15. http://beta.irri.org/news/index.php/200810134906/frontpage/Rice-Today/Rice-Today.html

Reyes LC, 2009b. Overcoming the toughest stress in rice. Rice Today 8: 30-32. http://beta.irri.org/news/index.php/200810134906/frontpage/Rice-Today/Rice-Today.html

Reynolds MP & Tuberosa R, 2008. Translational research impacting on crop productivity in drought-prone environments. Current Opinions in Plant Biology 11: 171 – 179.

Richards RA, 2006. Physiological traits used in the breeding of new cultivars for water-scarce environments. Agricultural Water Management 80: 197 – 211.

Riley H, Pommeresche R, Eltun R, Hansen S & Korsaeth A, 2008. Soil structure, organic matter and earthworm activity in a comparison of cropping systems with contrasting tillage, rotations, fertilizer levels and manure use. Agriculture, Ecosystems & Environment 124: 275.

Rodriguez RJ, Redman RS & Henson JM, 2004. The role of fungal symbioses in the adaptation of plants to high stress environments. Mitigation and Adaptation Strategies for Global Change 9: 261-272.

Rosenzweig C & Tubiello F, 2007. Adaptation and mitigation strategies in agriculture: an analysis of potential synergies. Mitigation and Adaptation Strategies for Global Change 12: 855-873.

Rost S, Gerten D, Hoff H, Lucht W, Falkenmark M & Rockström J, 2009. Global potential to increase crop production through water management in rainfed agriculture. Environmental Research Letters. doi: 10/1088/1748-9326/4/4/044002.

Schnable PS et al., 2009. The B73 maize genome: complexity, diversity, and dynamics. Science 326: 1112-1115.

Schubert D, 2003. A different perspective on GM food. (Commentary) Nature Biotechnology 20: 969. See also, Divergent opinions on GM food (Correspondence). Nature Biotechnology 20: 1195-1197.

Seager R, Ting M, Davis M, Cane M, Naik N, Nakamura J, Li C, Cook E & Stahle D, W. 2009. Mexican drought: An observational, modeling and tree ring study of variability and climate change. Atmosfera 22: 1-31.

Singh VK, Dwivedi BS, Shukla AK, Chauhan YS & Yadav RL, 2005. Diversification of rice with pigeonpea in a rice-wheat cropping system on a Typic Ustochrept: effect on soil fertility, yield and nutrient use efficiency. Field Crops Research 92: 85-105.

SIWI, 2001. Water harvesting for upgrading of rainfed agriculture. Problem analysis and research needs. By: Rockström J, Fox P, Persson G, and Falkenmark M. SIWI Report no 11, Stockholm, Sweden.

Smith P, Martino D, Cai DJ, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B & Sirotenko O, 2007. Agriculture. In: B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds). Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge and New York: University Press.

Stevens R, 2008. Prospects for using marker-assisted breeding to improve maize production in Africa. Journal of the Science of Food and Agriculture 88: 745–755.

Thomas RJ, 2008. Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. Agriculture, Ecosystems & Environment 126: 36-45.

Tilahun A, 1995. Yield gain and risk minimization in maize (Zea mays) through cultivar mixtures in semi-arid zones of the Rift Valley in Ethiopia. Experimental Agriculture 31: 161-168.

Tuiberosa R, Salvi S, Giuliani S, Sanguineti MC, Bellotti M, Conti S & Landi P, 2007. Genome-wide approaches to investigate and improve maize response to drought. Crop Science 47: S120-S141.

Wilkinson M & Tepfer M, 2009. Fitness and beyond: Preparing for the arrival of GM crops with ecologically important novel characters. Environmental Biosafety Research 8: 1-14.

Vogel B, 2009. Marker-Assisted Selection: a non-invasive biotechnology alternative to genetic engineering of plant varieties. Report prepared for Greenpeace International http://www.greenpeace.org/raw/content/international/press/reports/smart-breeding.pdf

Yadav RL, Dwivedi BS, Prasad K, Tomar OK, Shurpali NJ & Pandey PS, 2000. Yield trends, and changes in soil organic-C and available NPK in a long-term rice-wheat system under integrated use of manures and fertilisers. Field Crops Research 68: 219.

Zavaleta ES, Pasari JR, Hulvey KB & Tilman GD, 2010. Sustaining multiple ecosystem functions in grassland communities requires higher biodiversity. Proceedings of the National Academy of Sciences: published online before print January 4, 2010, doi:10.1073/pnas.0906829107.

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