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Enduring Farms: Climate Change, Smallholders and Traditional Farming Communities

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and Parviz Koohafkan

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Third World Network

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CHAPTER ONE

INTRODUCTION

THE threat of global climate change has caused concern among scientists as crop growth could be severely affected by changes in key climatic variables (i.e., rainfall and temperature) and agricultural production and food security could be affected both globally and locally. Although the effects of changes in climate on crop yields are likely to vary greatly from region to region, anticipated changes are expected to have large and far-reaching effects predominantly in tropical zones of the developing world with precipitation regimes ranging from semiarid to humid (Cline 2007). Hazards include increased flooding in low-lying areas, greater frequency and severity of droughts in semi-arid areas, and excessive heat conditions, all of which can limit crop growth and yields. The Intergovernmental Panel on Climate Change (IPCC) in its fourth Assessment report (IPCC 2007) warns that warming by 2100 will be worse than previously expected, with a probable temperature rise of 1.8°C to 4°C and a possible rise of up to 6.4°C. As temperatures continue to rise, the impacts on agriculture will be significant (Doering et al. 2002). These impacts are already being experienced by many communities in countries of the Southern hemisphere. There will also be an increase in droughts and heavy precipitation events, which will further damage crops through crop failure, flooding, soil and wind erosion. An increase in intense tropical cyclone activities will cause crop damage in coastal ecosystems, while sea level rise will reduce cropping areas and will salinize coastal aquifers. Pacific islands and large deltas are already being affected by these phenomena. Poor farmers in developing countries are especially vulnerable to these impacts of climate change because of their geographic exposure, low incomes, greater reliance on agriculture as well as limited capacity to seek alternative livelihoods.

However, in continuous coping with extreme weather events and climatic variability, farmers living in harsh environments in the regions of Africa, Asia and Latin America have developed and/or inherited complex farming systems that have the potential to bring solutions to many uncertainties facing humanity in an era of climate change. These systems have been managed in ingenious ways, allowing small farming families to meet their subsistence needs in the midst of environmental variability without depending much on modern agricultural technologies (Denevan 1995). Although many of these systems have collapsed or disappeared in many parts of the world, the stubborn persistence of millions of hectares under traditional farming is living proof of a successful indigenous agricultural strategy and constitutes a tribute to the “creativity” of small farmers throughout the developing world (Wilken 1987). Until today, well into the first decade of the 21st century, there are in the world millions of smallholders, family farmers and indigenous people practising resource-conserving farming which is testament to the remarkable resiliency of agroecosystems in the face of continuous environmental and economic change, while contributing substantially to food security at local, regional and national levels (Netting 1993).

CHAPTER TWO

AGRICULTURE, CLIMATE CHANGE AND THE RURAL POOR

OVER the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history. Between 1960 and 2005, the demand for ecosystem services grew significantly as the world population doubled to over 6 billion people and the global economy increased more than sixfold. To meet these growing demands, food production increased by roughly two-and-a-half times, water use doubled, wood harvests for pulp and paper production tripled, and timber production increased by more than half (Stockholm Environment Institute 2007). Agriculture is an essential component of societal well-being and it occupies 40 percent of the land surface, consumes 70 percent of global water resources and exploits biodiversity at genetic, species and ecosystem levels. At every point of production, agriculture influences and is influenced by ecosystems, biodiversity, climate and the economy. Modern agriculture is a fossil-fuel-energy-intensive industry and its development is tightly linked to energy factors, trade and globalization.

While the successes in agriculture production over the last decades are heralded, the inequitable distribution of benefits and unsustainable impacts on natural resources are becoming more evident. Undoubtedly, the acceleration of environmental degradation and climate change has direct effects on agricultural productivity and food security of over one billion people living in poverty in developing countries. The United Nations Food and Agriculture Organization (FAO)'s recent assessments have indicated that the target of the World Food Summit to reduce the number of food-insecure persons is not being met and that, despite the signing of major environmental agreements, carbon emissions continue to rise, species extinction is continuing and desertification continues to be of great concern in arid, semi-arid and sub-humid areas. World agriculture and forestry practices (e.g., conversion of wetlands to agriculture, deforestation, rice paddies, cattle feedlots, fertilizer use) today contribute about 25 percent to the emissions of greenhouse gases, while reducing carbon sinks and changing hydrological cycles, thus exacerbating climate change effects. In turn, the increasing frequency of storms, drought and flooding has implications on the viability of agroecosystems and global food availability.

Destabilization of long-established production systems via stresses such as water shortages, salinity, aridity and heat has increased, in the light of a growing demand for food which poses serious challenges to humankind. Furthermore, the expected increase of biofuel monoculture production may lead to increased rates of biodiversity loss and genetic erosion. A key challenge will be how to safeguard biodiversity for food and agriculture for future generations as well as maintain a broad gene pool which ensures ecosystem resilience.

With an increasing global population and overall purchasing power, more food calories are required while the availability of the necessary production factors is shrinking: forests are being converted to non-food production systems, water resources are scarcer, and climate change plus shrinking biodiversity are threatening the viability of farming communities in various settings. Today, there is no choice but to produce more with less, while deploying every effort to minimize production factors' risks. This means that environmental sustainability in agriculture is no longer an option but an imperative.

Using the results from formal economic models, it is estimated (Stern 2005) that in the absence of effective counteraction, the overall costs and risks of climate change will be equivalent to losing at least 5 percent of global gross domestic product (GDP) each year. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20 percent of GDP or more, with a disproportionate burden and increased risk of famine on the poorest countries. The costs of extreme weather events, including floods, droughts and storms, are already rising, including for developed countries. Without action, millions of people could become refugees as their homes and lands are hit by droughts or floods.

The majority of the world's rural poor, about 370 million of the poorest, live in areas that are resource-poor, highly heterogeneous and risk-prone. The worst poverty is often located in arid or semiarid zones, and in mountains and hills that are ecologically vulnerable (Conway 1997). In many countries, more people, particularly those at lower income levels, are now forced to live in marginal areas (i.e., floodplains, exposed hillsides, arid or semiarid lands), putting them at risk from the negative impacts of climate variability and change. For these vulnerable groups, even minor changes in climate can have disastrous impacts on their lives and livelihoods. Implications can be very profound for subsistence farmers located in remote and fragile environments, where yield decreases are expected to be very large, as these farmers depend on potentially affected crops (e.g., maize, beans, potatoes, rice, etc.) for their food security. Many researchers have expressed major concern over areas where subsistence agriculture is the norm, because a mere 1-ton yield decrease could lead to major disruption of rural life (Jones and Thornton 2003).

Agriculture and forestry, particularly many small farms and traditional agricultural systems still dotting landscapes throughout the developing world, can be part of the solution by contributing to climate change mitigation, through carbon conservation, sequestration and substitution, and establishing ecologically designed agricultural systems that can provide a buffer against extreme events. The diversity of these systems, and the creativity and knowledge of family farmers and indigenous communities are assets of great value for solving the daunting problems affecting agriculture in the 21st century.

CHAPTER THREE

IMPACTS OF CLIMATE CHANGE ON SMALLHOLDERS/TRADITIONAL FAMILY FARMING COMMUNITIES

APART from the landless and urban poor, small farmers are among the most disadvantaged and vulnerable groups in the developing world. The share of surveyed smallholder households falling below the poverty line is close to 55 percent in most continents. Most climate change models predict that damage will be disproportionately borne by small farmers, particularly rain-fed agriculturalists in the Third World. In some African countries, yields from rain-fed agriculture – the predominant form of agriculture in Africa – could be reduced by 50 percent by 2020. Additionally, agricultural production in many African countries is projected to be severely compromised especially in drylands. About 70 percent of Africans depend directly on dry and sub-humid lands for their daily livelihoods.

Jones and Thornton (2003) predict an overall reduction of 10 percent in maize production in the year 2055 in Africa and Latin America, equivalent to losses of $2 billion per year, affecting principally 40 million poor livestock keepers in mixed systems of Latin America and 130 million in those of sub-Saharan Africa. These yield losses will intensify as temperatures increase and rainfall differences are less conducive to maize production. It is obvious that climate-related environmental stresses are likely to affect individual households differently compared to more market-oriented farmers. Some researchers predict that as climate change reduces crop yields, the effects on the welfare of subsistence farming families may be quite severe, especially if the subsistence component of productivity is reduced. Changes in quality and quantity of production may affect the labour productivity of the farmer and negatively influence his/her family health (Rosenzweig and Hillel 1998).

Global warming is predicted to result in a variety of physical effects including thermal expansion of sea water, along with partial melting of land-based glaciers and sea-ice, resulting in a sea level rise which may range from 0.1 to 0.5 metres by the middle of the next century, according to present IPCC estimates. The IPCC has projected potential impacts of climate change which could adversely affect agricultural production and food security (Box 1). A sea level rise could pose a threat to agriculture in low-lying coastal areas, where impeded drainage of surface water and of groundwater, as well as intrusion of sea water into estuaries and aquifers, might take place. In parts of Egypt, Bangladesh, Indonesia, China, and other low-lying coastal areas already suffering from poor drainage, agriculture is likely to become increasingly difficult to sustain. Some island states are particularly at risk (Rosenzweig and Hillel 2008).

A climate change impact potentially significant to small farm production is loss of soil organic matter due to soil warming. Higher air temperatures are likely to speed the natural decomposition of organic matter and to increase the rates of other soil processes that affect fertility. Under drier soil conditions, root growth and decomposition of organic matter are significantly suppressed, and as soil cover diminishes, vulnerability to wind erosion increases, especially if winds intensify. In some areas, an expected increase in convective rainfall – caused by stronger gradients of temperature and pressure and more atmospheric moisture – may result in heavier rainfall, which can cause severe soil erosion.

Box 1. Possible impacts of climate change on agriculture, forestry and ecosystems

Affected Region	Potential Impacts
Africa	By 2025, approximately 480 million people in Africa could be living in water-scarce or water-stressed areas. By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50 percent. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition.
Asia	By the 2050s, freshwater availability in Central, South, East, and Southeast Asia, particularly in large river basins, is projected to decrease.
Latin America	By mid-century, increases in temperature and associated decreases in soil water are projected to lead to a gradual replacement of tropical forest by savannah in eastern Amazonia. Semiarid vegetation will tend to be replaced by arid-land vegetation. Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones, soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase.

Source: FAO (2008), based on information from IPCC (2007)

Conditions are usually more favourable for the proliferation of insect pests in warmer climates. Longer growing seasons may enable a number of insect pest species to complete a greater number of reproductive cycles during the spring, summer, and autumn. Warmer winter temperatures may also allow larvae to winter-over in areas where they are now limited by cold, thus causing greater infestation during the following crop season. Most studies have concluded that insect pests will generally become more abundant as temperatures increase, through a number of inter-related processes, including range extensions and phenological changes, as well as increased rates of population development, growth, migration and over-wintering. Migrant pests are expected to respond more quickly to climate change than plants, and may be able to colonize newly available crops/habitats. A gradual, continuing rise in atmospheric carbon dioxide (CO_2) will affect pest species directly (i.e., the CO_2 fertilization effect) and indirectly (via interactions with other environmental variables). However, individual species' responses to elevated CO_2 levels vary: consumption rates of insect herbivores generally increase, but this does not necessarily compensate fully for reduced leaf nitrogen. The consequent effects on performance are strongly mediated via the host species. Some recent experiments under elevated CO_2 have suggested that aphids may become more serious pests, although other studies have discerned no significant effects on sap-feeding homopterans. However, few, if any, of these experiments have fully considered the effects on pest population dynamics.

Models on plant diseases indicate that climate change could alter stages and rates of development of certain pathogens, modify host resistance, and result in changes in the physiology of host-pathogen interactions. The most likely consequences are shifts in the geographical distribution of host and pathogen and increased crop losses, caused in part by changes in the efficacy of control strategies. Altered wind patterns may change the spread of bacteria and fungi that are the agents of wind-borne plant diseases. The limited literature in this area suggests that the most likely impact of climate change will be felt in three areas: in losses from plant diseases, in the efficacy of disease management strategies and in the geographical distribution of plant diseases. Climate change could have positive, negative or no impact on individual plant diseases, but with increased temperatures and humidity many pathogens are predicted to increase in severity.

The possible increases in pest and disease infestations may bring about greater use of chemical pesticides to control them, a situation that may enhance production costs and also increase environmental problems associated with agrochemical use. Of course, this may not be the case with farmers who use polycultures, agroforestry or other forms of diversified cropping systems that prevent insect pest buildup either because one crop may be planted as a diversionary host, protecting other, more susceptible or more economically valuable crops from serious damage, or because crops grown simultaneously enhance the abundance of predators and parasites which provide biological suppression of pest densities (Altieri and Nicholls 2004).

CHAPTER FOUR

STRENGTHS AND WEAKNESSES OF TRADITIONAL FARMING SYSTEMS IN AN ERA OF CLIMATE CHANGE

OVER the centuries, generations of farmers and herders have developed complex, diverse and locally adapted agricultural systems, managed with time-tested, ingenious combinations of techniques and practices that lead to community food security and the conservation of natural resources and biodiversity. These microcosms of agricultural heritage can still be found throughout the world, covering some 5 million hectares, and providing a series of ecological and cultural services to humankind such as the preservation of traditional forms of farming knowledge, local crop and animal varieties and autochthonous forms of socio-cultural organization. These systems represent the accumulated experiences of peasants interacting with their environment using inventive self-reliance, experiential knowledge, and locally available resources. These agroecosystems that are of global importance to food and agriculture are based on cultivation of a diversity of crops and varieties in time and space that have allowed traditional farmers to avert risks and maximize harvest security in uncertain and marginal environments, under low levels of technology and with limited environmental impact.

One of the salient features of the traditional farming systems is their high degree of biodiversity, in particular the plant diversity in the form of polycultures and/or agroforestry patterns. This strategy of minimizing risk by planting several species and varieties of crops is more adaptable to weather events, climate variability and change and resistant to adverse effects of pests and diseases, and at the same time stabilizes yields over the long term, promotes diet diversity and maximizes returns even with low levels of technology and limited resources. Such biodiverse farms are endowed with nutrient-enriching plants, insect predators, pollinators, nitrogen-fixing and nitrogen-decomposing bacteria, and a variety of other organisms that perform various beneficial ecological functions. By properly assembling a functional biodiversity (that is, a collection of organisms that play key functions in the farm), it is possible to promote synergy which enhances farm processes such as the activation of soil biology, the recycling of nutrients, the enhancement of biological pest suppression, etc., all important in determining the performance of agroecosystems. Although these systems evolved in very different times and geographical areas, they share structural and functional commonalities (Beets 1990; Marten 1986), such as:

- They combine species and structural diversity in time and space through both vertical and horizontal organization of crops.
- The higher biodiversity of plants, microbes, and animals inherent to these systems supports production of crops and stock and mediates a reasonable degree of biological recycling of nutrients.
- They exploit the full range of micro-environments, which differ in soil, water, temperature, altitude, slope, and fertility within a field or region.
- They maintain cycles of materials and wastes through effective recycling practices.
- They rely on biological interdependencies that provide some level of biological pest suppression.

- They rely on local resources plus human and animal energy, using little modern technology.
- They rely on local varieties of crops and incorporate wild plants and animals. Production is usually for local consumption.

Recent observations, studies and research suggest that many farmers cope and even prepare for climate change, minimizing crop failure through increased use of drought-tolerant local varieties, water harvesting, extensive planting, mixed cropping, agroforestry, opportunistic weeding, wild plant gathering and a series of other traditional farming system techniques. This points to the need to re-evaluate indigenous technology as a key source of information on adaptive capacity centred on the selective, experimental and resilient capabilities of farmers in dealing with climate change.

Observations of agricultural performance after extreme climatic events in the last two decades have revealed that resiliency to climate disasters is closely linked to levels of farm biodiversity. A survey conducted in hillsides after Hurricane Mitch in Central America showed that farmers using diversification practices such as cover crops, intercropping and agroforestry suffered less damage than their conventional neighbours using monocultures. The survey, spearheaded by the Campesino a Campesino movement, mobilized 100 farmer-technician teams and 1,743 farmers to carry out paired observations of specific agroecological indicators on 1,804 neighbouring sustainable and conventional farms. The study spanned 360 communities and 24 departments in Nicaragua, Honduras and Guatemala. It was found that sustainable plots had 20 to 40 percent more topsoil, greater soil moisture and less erosion and experienced lower economic losses than their conventional neighbours (Holt-Gimenez 2001).

The 1991/92 drought had a crippling effect over much of Southern Africa, with many countries in the region having seasonal deficits of up to 80 percent of normal rainfall. There were unprecedented crop failures. The region, usually a food exporter, had to import 11.6 million tons of food worth over US$4 billion. Regional grain production fell some 60 percent short of expected levels. The drought led to widespread hunger and malnutrition with loss of cattle and crops. Farmers' responses to the effects of the drought were varied. In Zimbabwe, farmers, especially women in Nyanga, Chipinge, Mudzi, Chivi and Gwanda districts, undertook many actions to mitigate drought and these resulted in at least some level of food security. The following are some of the measures employed:

- ***Permaculture*:** Helps farmers prepare for drought through land use designs that enhance crop diversity and water conservation.
- ***Water harvesting*:** Farmers harvest water from rooftops and divert water from natural springs into tanks. This ensures that they have a substantial amount of water stored up. In case of a drought, the stored water will be able to sustain them for about five months depending on the volume of the tank. The water is also used for supplementary irrigation of vegetables and crops.
- ***Infiltration pits*:** Some farmers dig infiltration pits along contours. Water collects in the pits during the rainy period. When the weather becomes dry, as in the case of a short period of rains, the water infiltrates underground and is used by the plants. Crops can grow up to maturity by using this conserved moisture. Farmers' experience shows that even if there are only five days with rain in the whole rainy season, the crops will reach maturity using conserved and harvested water in the pits.

- ***Granaries*:** Most farmers store food to be used in case of a drought. They have a specific granary stocked with grain (sorghum, millets, and maize for a shorter period of time), especially those resistant to post-harvest pests.
- ***Drought-tolerant crops*:** Many farmers prefer the use of traditional grains such as millets and sorghums that are more drought-resistant than maize and therefore give a good yield even with very little rain. Farmers also prefer specific crop varieties for drought seasons, such as an indigenous finger millet variety (chiraufe), a cucurbit (Nyamunhororo), as it ripens fast, and an early maturing cowpea (*Vigna unguiculata*) variety.

These examples are of great significance as they point the way for resource-poor farmers living in marginal environments, providing the basis for adaptive natural resource management strategies that privilege the diversification of cropping systems which lead to greater stability and ecological resiliency under climatic extremes.

CHAPTER FIVE

EXTENT OF TRADITIONAL AND FAMILY FARMING SYSTEMS

IN *Latin America*, peasant production units numbered about 16 million in the late 1980s, occupying close to 60.5 million hectares, or 34.5 percent of the total cultivated land; the peasant population includes 75 million people, representing almost two-thirds of Latin America's total rural population (Ortega 1986). The average farm size of these units is only about 1.8 hectares; however, the contribution of peasant agriculture to the general food supply in the region is significant. In the 1980s, it reached approximately 41 percent of the agricultural output for domestic consumption, and mainly is responsible for producing, at the regional level, 51 percent of the maize, 77 percent of the beans, and 61 percent of the potatoes. In Brazil alone, there are about 4.8 million traditional family farmers (about 85 percent of the total number of farmers) that occupy 30 percent of the total agricultural land of the country. Such family farms control about 33 percent of the area sown to maize, 61 percent of that under beans, and 64 percent of that planted to cassava, thus producing 84 percent of the total cassava and 67 percent of all beans. In Ecuador, the peasant sector occupies more than 50 percent of the area devoted to food crops such as maize, beans, barley and okra. In Mexico, peasants occupy at least 70 percent of the area assigned to maize and 60 percent of the area under beans (Toledo et al. 1985). In addition to the peasant and family farm sector, there are about 50 million individuals belonging to some 700 different indigenous ethnic groups who live in and utilize the humid tropical regions of the world. About 2 million of these live in the Amazon and southern Mexico. In Mexico, half of the humid tropics are utilized by indigenous communities and *ejidos*[1] featuring integrated agriculture-forestry systems with production aimed at subsistence and local-regional markets (Toledo et al. 1985).

Africa has approximately 33 million small farms, representing 80 percent of all farms in the region. The majority of African farmers (many of them are women) are smallholders, with two-thirds of all farms below 2 hectares and 90 percent of farms below 10 hectares. Most small farmers practise "low-resource" agriculture which is based primarily on the use of local resources, but which may make modest use of external inputs. Low-resource agriculture produces the majority of grains, almost all root, tuber and plantain crops, and the majority of legumes. Most basic food crops are grown by small farmers with virtually no or little use of fertilizers and improved seed (Richards 1985). This situation, however, has changed in the last two decades as food production per capita has declined in Africa. Once self-sufficient in cereals, Africa now has to import millions of tons to fill the gap. Despite this increase in imports, smallholder or small-scale farmers still produce most of Africa's food (Beets 1990).

In *Asia*, China alone accounts for almost half the world's small farms (193 million hectares), followed by India with 23 percent, and Indonesia, Bangladesh, and Viet Nam. In Asia there are more than 200 million rice farmers, most of whom grow their crops on small 2-hectare pieces of land. In China alone, there

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[1] The *ejido* system is a system of land tenure in which usually the government promotes the use of communal land shared by the people of the community. This use of community land was a common practice during the time of Aztec rule in Mexico.

are probably 75 million rice farmers who still practise farming methods similar to those used more than 1,000 years ago. Local cultivars, grown mostly on upland ecosystems and/or under rain-fed conditions, make up the bulk of the rice produced by Asian small farmers (Uphoff 2002).

CHAPTER SIX

COPING MECHANISMS AND STRATEGIES TO ENHANCE RESILIENCY TO CLIMATIC VARIABILITY

COPING with chronically variable yields of food crops is critical for the survival of farm households in marginal environments where agro-climatic conditions are challenging. Land degradation, brought about through a prolonged interface between human-induced and natural factors, exacerbates low productivity. Managing risk exposure is an important preoccupation of agricultural households in such environments and the only insurance mechanism available to these farmers is derived from the use of inventive self-reliance, experiential knowledge, and locally available resources.

In many areas of the world peasants have often developed farming systems adapted to the local conditions, enabling farmers to generate sustained yields to meet their subsistence needs, despite marginal land endowments, climatic variability and low use of external inputs (Wilken 1987; Denevan 1995). Part of this performance is linked to the high levels of agrobiodiversity exhibited by traditional agroecosystems, which in turn positively influence agroecosystem function (Vandermeer (ed.) 2002). Diversification is therefore an important farm strategy for managing production risk in small farming systems.

In traditional agroecosystems the prevalence of complex and diversified cropping systems is of key importance to the stability of peasant farming systems, allowing crops to reach acceptable productivity levels in the midst of environmentally stressful conditions. In general, traditional agroecosystems are less vulnerable to catastrophic loss because they grow a wide range of crops and varieties in various spatial and temporal arrangements. Examples of the coping mechanisms and strategies used by smallholder/traditional family farming communities to enhance resiliency against climatic variability are:

a) Multiple cropping or polyculture systems

By employing multiple cropping or polyculture systems, traditional farmers can adapt to local conditions, and sustainably manage harsh environments and meet their subsistence needs without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science. Indigenous farmers tend to combine various production systems as part of a typical household resource management scheme. The practice of multiple cropping systems enables smallholder farmers to achieve several production and conservation objectives simultaneously. Furthermore, polycultures exhibit greater yield stability and less productivity declines during a drought than in the case of monocultures. Natarajan and Willey (1986) examined the effect of drought on enhanced yields with polycultures by manipulating water stress on intercrops of sorghum (*Sorghum bicolor*) and peanut (*Arachis* spp.), millet (*Panicum* spp.) and peanut, and sorghum and millet. All the intercrops overyielded consistently at five levels of moisture availability, ranging from 297 to 584 mm of water applied over the cropping season. Quite interestingly, the rate of overyielding actually increased with water stress, such that the relative differences in productivity between monocultures and polycultures became more accentuated as stress increased. These types of ecological studies suggest that more diverse plant communities are more resistant to disturbance and more resilient to environmental perturbations (Vandermeer (ed.) 2002).

b) Wild plant gathering

In many parts of the developing world, the peasant sector still obtains a significant portion of its subsistence requirements from wild plants in and around crop fields (Altieri et al. 1987). In many agropastoral African societies, collection of edible leaves, berries, roots, tubers, fruits, etc. in the bushlands surrounding the villages constitutes an important strategy for diversification of the food base. During droughts or other times of environmental stress, many plants are gathered and consumed, and studies in northeastern Tanzania on the use of *michicha* (wild green leafy vegetables) show that these plants provide significant amounts of carotene, calcium, iron and protein to the peasant diet (Fleuret 1979). Gathering is also practised in Mexico by the Puerpecha Indians, who use more than 224 species of wild native and naturalized vascular plants for dietary, medicinal, household, and fuel needs. Similarly, in the Mexican Huasteca, indigenous people use about 125 plant species and in Uxpanapa local farmers exploit about 445 wild plant and animal species, of which 229 are used as food (Toledo et al. 1985). In many regions, farmers voluntarily leave weeds in the fields by relaxing weed control. The Tarahumara Indians in the Mexican Sierras depend on edible weed seedlings (quelites) from April through July, a critical period before maize, beans, chiles and cucurbits mature in the planted fields from August through October, thus practising a double crop system of maize and weeds that allows for two harvests. Quelites also serve as the only alternative food supply when crops are destroyed by hail or drought (Bye 1981).

c) Agroforestry systems and mulching

Many farmers grow crops in agroforestry designs and shade tree cover to protect crop plants against extremes in the microclimate and soil moisture fluctuation. Farmers influence the microclimate by retaining and planting trees, which reduce temperature, wind velocity, evaporation and direct exposure to sunlight and intercept hail and rain. Lin (2007) found that in coffee agroecosystems in Chiapas, Mexico, temperature, humidity and solar radiation fluctuations increased significantly as shade cover decreased; thus, it was concluded that shade cover was directly related to the mitigation of variability in the microclimate and soil moisture for the coffee crop. Away from the humid and warm environment of the lowland tropics and into drier environments such as northeastern Brazil, cultivation of babassu palm (*Orbignya phalerata*) in grazing areas provides shade for cattle, while in agriculturally oriented places, it serves as shade for rice, maize, cassava and even bananas and plantains, ameliorating the microclimate and reducing soil water loss. In some systems, farmers plant cashew trees to provide shelter for other productive crops such as sorghum, groundnuts and sesame (Johnson and Nair 1985). Clearly, the presence of trees in agroforestry designs stands out as a key strategy for mitigation of microclimate variability in smallholder farming systems.

Many farmers also apply mulches of ground-covering plants or straw to reduce radiation and heat levels on newly planted surfaces, inhibit moisture losses, and absorb the kinetic energy of falling rain and hail. When night frost is expected, some farmers burn straw or other waste materials to generate heat and produce smog, which traps outgoing radiation. The raised planting beds, mounds, and ridges often found in traditional systems serve to control soil temperatures and to reduce waterlogging by improving drainage (Wilken 1987; Stigter 1984).

Today it is internationally recognized that agroforestry systems contribute simultaneously to buffering farmers against climate variability and changing climates, and to reducing atmospheric loads of greenhouse gases because of their high potential for sequestering carbon. In addition, net greenhouse gas emissions from agroforestry systems are lower per unit of economic productivity than other agricultural intensification options. In many surveyed areas, results show that farmers suffer lower levels of weather-related crop failure through the expansion of agroforestry systems (http://www.worldagroforestrycentre.org/es/climate_change.asp).

d) Home gardening

In one of the oldest traditional forms of agriculture, humans in the humid tropics imitated nature in their agricultural practices through integrating trees (fruit-bearing trees and fodder trees) and other perennials as components of an elaborately constructed home garden, with a mixture of crops, mostly vegetables, herbs and other ornamentals. This type of home gardening is still prevalent in many areas of the humid tropics in India. Home gardens are small plots either in the backyard or located close to the habitation. They are fertilized with household wastes and are rich in plant species diversity, usually maintaining 30 to 100 species. This practice provides diversification of crop species and is of economic importance because of its food and nutritional (balanced diet) and medicinal value to the household. The farmer obtains food products, firewood, medicinal plants, spices and ornamentals, and some cash income all year round. These self-sustaining systems are ecologically and economically very efficient. Aside from being an important system to support livelihood strategies of the farmers, gardening also plays a crucial role in the conservation of diverse species in a single household unit by maintaining various annual, biannual and perennial plants at home and by offering a repository and domestication experimentation site for many plant varieties.

Box 2. Home gardens of Mexico and Belize

Home gardens are important agroecological systems in many cultural landscapes in the tropics and subtropics. Mixed tree systems or home gardens are common in the lowlands of Mexico, where they constitute a common but understudied form of agriculture. Home gardens in Mexico are plots of land that include a house surrounded by or adjacent to an area for raising a variety of plant species and sometimes livestock. The home garden is representative of a household's needs and interests, providing food, fodder, firewood, market products, construction materials, medicines, and ornamental plants for the household and local community. Many of the more common trees are those same species found in the surrounding natural forests, but new species have also been incorporated, including papaya (*Carica papaya*), guava (*Psidium* spp.), banana (*Musa* spp.), lemon (*Citrus limon*) and orange (*Citrus aurantium*). In light gaps or under the shade of trees, a series of both indigenous and exotic species of herbs, shrubs, vines and epiphytes is grown. Seedlings from useful wild species brought into the garden by the wind or animals are often not weeded out and are subsequently integrated into the home garden system. The Mopane Maya of Southern Belize have home gardens that are multi-storied and contain a mixture of minor crops, fruits, ornamental and medicinal plants, representing around a dozen tree, shrub and herb species.

e) Use of local genetic diversity

In addition to adopting a strategy of *interspecific diversity*, many resource-poor farmers also exploit *intraspecific diversity* by growing, at the same time and in the same field, different cultivars of the same crop. In a worldwide survey of crop varietal diversity on farm involving 27 crops, Jarvis et al. (2007) found that considerable crop genetic diversity continues to be maintained on farm in the form of traditional crop varieties, especially of major staple crops. In most cases, farmers maintain diversity as insurance against future environmental change or to meet social and economic needs. Many researchers have concluded that variety richness enhances productivity and reduces yield variability, but as Di Falco et al. (2007) found in their study of wheat genetic diversity in the highlands of Ethiopia, the richness must reach a certain threshold level, as apparently reduced yield variability only occurs at high levels of genetic diversity. These researchers also found that the effect of diversity on yield variance varied with land degradation. Increased land degradation tended to negate the effects of diversity on reducing production risks.

The type of diversity which prevails in different areas depends on both climatic and socioeconomic conditions and farmers' response. For example, in the dry areas of West Asia and North Africa, barley is often the only feasible rain-fed crop, especially the cultivars which have been grown for centuries and are genetically heterogeneous. Similarly, in rainfall-limited environments of India, locally adapted varieties of pigeon pea (*Cajanus cajan*) uniquely combine optimal nutritional profiles, high tolerance to environmental stresses, high biomass productivity and nutrient and moisture contributions to the soil. These varieties that exhibit high genetic variability have a huge untapped potential to be grown in many marginal environments of Africa and elsewhere threatened by climate change. Generally, in areas with little moisture, farmers prefer drought-tolerant crops (like *Cajanus cajan*, sweet potato, cassava, millet, and sorghum), and management techniques emphasize soil cover (such as mulching) to reduce moisture evaporation and soil runoff.

Landraces have specific morphological and physiological traits that render them suitable for dry environments. Of all the measured variables that showed a general trend for greater drought resistance in sorghum landraces, only osmotic adjustment under stress was generally correlated with average rainfall at each race's origin, indicating greater osmotic adjustment in landraces from drier regions. Races with a greater capacity for osmotic adjustment were characterized by smaller plants with high rates of transpiration and low rates of leaf senescence under stress. In the case of millet landraces, the commonly observed adaptation of the millets to dry environments was more due to drought escape and/or heat tolerance.

The existence of genetic diversity has special significance for the maintenance and enhancement of productivity of small farming systems, as diversity also provides security to farmers against diseases, especially pathogens that may be enhanced by climate change. By mixing crop varieties, farmers can delay the onset of diseases by reducing the spread of disease-carrying spores, and by modifying environmental conditions so that they are less favourable to the spread of certain pathogens. This aspect was well demonstrated by researchers working with farmers in 10 townships in Yunnan, China, covering an area of 5,350 hectares. The farmers were encouraged to switch from rice monocultures to planting variety mixtures of local rice with hybrids. The enhanced genetic diversity reduced blast incidence by 94 percent and increased total yields by 89 percent. After two years, it was concluded that fungicides were no longer required (Zhu et al. 2000).

Box 3. Diversification of crops

Farmers in Southern Ghana are adapting and coping with climate variability in various ways. These mechanisms are manifested by the diversity of resource management and cropping systems, which are based on indigenous knowledge of management of the fragile and variable environment, local genotypes of food crops, intercropping, and agroforestry systems. These coping mechanisms not only help meet the farmers' subsistence needs but also encourage biodiversity conservation. To offset crop failure arising from rainfall variability and unpredictability, farmers cultivate several hardier (or drought-tolerant) types of the same crop species. Also, planting of vegetable crops that can serve as a hedge against risk associated with drought is a common practice.

Source: Ofori-Sarpong and Asante (2004)

f) Soil organic matter enhancement

Soils hold about 75 percent of terrestrial carbon and show a greater potential to sequester much more carbon than trees. But in addition to carbon sequestration and affecting both the chemical and physical properties of the soil such as soil structure, diversity and activity of soil organisms, and nutrient availability, organic matter enhances the water holding capacity of the soil via several mechanisms:

- Plant residues that cover the soil surface protect the soil from sealing and crusting by raindrop impact, thereby enhancing rainwater infiltration and reducing runoff. Increased organic matter also contributes indirectly to soil porosity (via increased soil faunal activity). The consequence of increased water infiltration combined with a higher organic matter content is increased soil storage of water.

- The addition of organic matter to the soil usually increases the water holding capacity of the soil. This is because the addition of organic matter increases the number of micropores and macropores in the soil either by "gluing" soil particles together or by creating favourable living conditions for soil organisms. Certain types of soil organic matter can hold up to 20 times their weight in water (Wilken 1987; Denevan 1995).

Throughout the world, small farmers use practices such as crop rotation, composting, green manures and cover crops, agroforestry, etc., all practices that increase biomass production and therefore build active organic matter. Soil management systems that lead to maintenance of soil organic matter levels are essential to the sustained productivity of agricultural systems in areas frequently affected by droughts.

CHAPTER SEVEN

GLOBALLY IMPORTANT AGRICULTURAL HERITAGE SYSTEMS

EVEN in the 21st century and despite the expansion of modern agriculture, millions of hectares still persist under ancient, traditional agricultural management. These microcosms of ancient agriculture are living examples of successful indigenous agricultural strategy and comprise a tribute to the “creativity” of traditional farmers and indigenous peoples. Many of these agricultural systems are documented and some of them have been selected for piloting dynamic conservation under FAO’s “Globally Important Agricultural Heritage Systems (GIAHS)” initiative. The initiative offers promising models of sustainability which promote agricultural biodiversity while sustaining year-round yields without too much dependency on agrochemicals (Altieri 1995). GIAHS have resulted not only in outstanding aesthetic beauty, maintenance of globally significant agricultural biodiversity, resilient ecosystems and valuable cultural inheritance, but, above all, in the sustained provision of multiple goods and services, food and livelihood security and quality of life for millions of people. These systems exhibit important elements of sustainability even in times of unpredictable climate variability, namely: they are well adapted to their particular environment, rely on local resources, are small-scale and decentralized, tend to conserve the natural resource base and exhibit resiliency to environmental change. Because of their significance and the wealth and breadth of accumulated knowledge and experience in the management and use of resources that GIAHS represent, it is imperative that they be considered globally significant resources and be protected and dynamically conserved as well as allowed to evolve. Such ecological and cultural resources are of fundamental value for the future of humankind, especially because many of them represent systems that have adapted to changing climatic and environmental conditions through centuries. Examples of Globally Important Agricultural Heritage Systems of relevance to climate change include:

A) Raised field agriculture

i) Chinampas *of Mexico*

Raised field agriculture is an ancient food production system used extensively by the Aztecs in the Valley of Mexico but also found in China, Thailand, and other areas to exploit permanently flooded areas or swamplands bordering lakes. Called *chinampas* in the Aztec region, these "islands" or raised platforms (from 2.5 to 10 metres wide and up to 100 metres long) were usually constructed with mud scraped from the surrounding swamps or shallow lakes. The Aztecs built their platforms up to a height of 0.5 to 0.7 metres above water levels and reinforced the sides with posts interwoven with branches and with trees planted along the edges (Armillas 1971).

The soil of the platforms is constantly enriched with organic matter produced with the abundant aquatic plants, as well as with sediments and muck from the bottom of the reservoirs. A major source of organic matter today is the water hyacinth (*Eichornia crassipes*), capable of producing up to 900 kg per hectare of dry matter daily. Supplemented with relatively small amounts of animal manure, the *chinampas* can be made essentially self-sustaining. Animals such as pigs, chickens and ducks are kept in small corrals and fed the excess or waste produce from the *chinampas*. Their manure is incorporated back into the platforms (Gliessman 1998). On the *chinampas*, farmers concentrate the production of their basic food crops as well as vegetables. These include the traditional corn/bean/squash polyculture, cassava/corn/bean/peppers/amaranth, the fruit trees associated with various cover crops, shrubs, or vines. Farmers also encourage the growth of fish in the water courses.

The high levels of productivity that characterize the *chinampas* result from several factors. First, cropping is nearly continuous; only rarely is the *chinampa* left without a crop. As a result, 3 to 4 crops are produced each year. One of the primary mechanisms by which this intensity is maintained is the seedbeds, in which young plants are germinated before the older crops are harvested. Second, the *chinampas* maintain a high level of soil fertility despite the continual harvest of crops because they are supplied with high quantities of organic fertilizers. The lakes themselves serve as giant catch basins for nutrients. The aquatic plants function as nutrient concentrators, absorbing nutrients that occur in low concentration in the water and storing them inside their tissue. The use of these plants along with canal mud and muddy water (for irrigation) ensures that an adequate supply of nutrients is always available to the growing crops. Third, there is plenty of water for the growing crop. The narrowness of the *chinampas* is a design feature that ensures that water from the canal infiltrates the *chinampa*, giving rise to a zone of moisture within reach of the crop's roots. Even if during the dry season the lake levels fall below the rooting zone, the narrowness of the *chinampa* allows the *chinampero* to irrigate from a canoe. Fourth, there is a large amount of individual care given to each plant in the *chinampa*. Such careful husbandry facilitates high yields (Gliessman 1998).

ii) Waru-Warus of Titicaca

Researchers have uncovered remnants of more than 170,000 ha of “ridged fields” in Surinam, Venezuela, Colombia, Ecuador, Peru, and Bolivia (Denevan 1995). Many of these systems apparently consisted of raised fields on seasonally-flooded lands in savannahs and in highland basins. In Peru, many researchers have studied such pre-Columbian technologies in search of solutions to contemporary problems, especially the frost that is so ubiquitous in high-altitude farming. A fascinating example is the revival of an ingenious system of raised fields that evolved on the high plains of the Peruvian Andes about 3,000 years ago. According to archaeological evidence, these Waru-Warus – platforms of soil surrounded by ditches filled with water – were able to produce bumper crops, despite floods, droughts, and the killing frost common at altitudes of nearly 4,000 m (Erickson 1985).

The combination of raised beds and canals has proven to have important temperature moderation effects, extending the growing season and leading to higher productivity on the Waru-Warus compared to chemically fertilized normal pampa soils. In the Huatta district, reconstructed raised fields produced impressive harvests, exhibiting a sustained potato yield of 8-14 tonnes/ha/yr. These figures contrast favourably with the average Puno potato yields of 1-4 tonnes/ha/yr. In Camjata the potato fields reached 13 tonnes/ha/yr in Waru-Warus. It is estimated that the initial construction, rebuilding every 10 years, and annual planting, weeding, harvest and maintenance of raised fields planted require 270 person-days/ha/yr.

B) Mountain agriculture in the Andes

The impact of the complex Andean environment on the human economy has resulted in vertical arrangements of settlements and agricultural systems. The pattern of verticality derives from climatic and biotic differences related to altitude and geographical location. The most important cultural adaptation to these environmental constraints has been the subsistence system: crops, animals, and agropastoral technologies designed to yield an adequate diet with local resources while avoiding soil erosion (Gade 1999).

The evolution of agrarian technology in the Central Andes has produced extensive knowledge about using the Andean environment. This knowledge affected the division of the Andean environment into altitudinally arranged agroclimatic belts, each characterized by specific field and crop rotation practices, terraces and irrigation systems, and the selection of many animals, crops, and crop varieties (Brush (ed.) 2000). About 34 different crops (corn, quinoa, *Amaranthus caudatus*, legumes, beans, lupine, lima beans), tubers (species of potato, manioc, *Arrachocha*, etc.), fruits, condiments, and vegetables are grown. The main crops are corn chenopods (*Chenopodium quinoa* and *C. pallidicaule*), and potatoes. Individual farmers may cultivate as many as 50 varieties of potatoes in their fields, and up to 100 locally named varieties may be found in a single village. The maintenance of this wide genetic base is adaptive since it reduces the threat of crop loss due to pests and pathogens specific to particular strains of the crop (Brush (ed.) 2000). Farmers also manage a series of plots located in different belts to reduce the frequency of failure, because if frost or drought hits one belt, the farmers can always harvest crops from unaffected altitudinal belts.

Crops are also located in the mountain depending on their adaptation to altitude, moisture, temperature, vegetation, land tenure, crop assemblages, and agricultural technology. There is considerable regional variation in the cultivation patterns of each belt. For example, in the communities of Amaru and Paru-Paru in Cuzco, Peru, three main belts can be distinguished (Gade 1999). Sites in the corn belt have soft slopes, located between 3,400 and 3,600 metres, and farmers practise three alternative four-year rotations. The potato/fava/cereals belt is composed of sites with steep slopes, located from 3,600 to 3,800 metres. Potatoes are intercropped with barley, wheat, fava beans and peas. In rain-fed areas, fava beans and *Lupinus mutabilis* are key components of the rotation. The bitter potato-pasture belt is a cold belt located about 3,800 metres. Rain-fed rotations in this belt usually include potato/*Oyxalis tuberosa*/ *Ullucus tuberosus* and *Trapaeolum tuberosum*/barley.

C) Quezungal farming system

The indigenous and traditional societies in the remote village of Guarita, Honduras protect their watershed through the traditional Quezungal farming system. The system involves planting crops under trees whose roots anchor the soil, pruning vegetation to provide nutrients to the soil and to conserve soil and water, and terracing to reduce soil erosion. This farming system avoids widespread slash-and-burn techniques. Through practising this farming system, the local community was one of the few places in the region that successfully avoided the worst destruction from Hurricane Mitch in 1998 (Bergkamp et al. 2003).

D) Ifugao rice terraces

Rice terraces cascading down the slope of Ifugao, Philippines present a spectacular vista. They are the fruits of labour of countless generations of farmers who have developed an ingenious irrigation system that has allowed them to share water and develop rice varieties that survive at over 1,000 metres under local conditions. The Ifugao rice terraces are a model of a holistic farming system that features a balanced agroecosystem interlocked with “harmony between humankind and the environment”. Their ancient characteristics and features, spectacular aesthetic beauty and value have earned the rice terraces a spot on the UNESCO World Heritage List. The rice terraces are supported by indigenous knowledge management of *muyong*, a private forest that caps each terrace cluster. The *muyong* is managed through a collective effort and under traditional tribal practices. The communally managed forestry area on top of the terraces mostly contains about 264 indigenous plant species, mostly endemic to the region. The terraces form unique clusters of micro-watersheds and are part of the whole mountain ecology. They serve as a rainwater and filtration system and are saturated with irrigation water all year round. Despite increasing pressures of modernization and global change, many Ifugao have maintained their traditional *agri-cultural* practices – the biorhythm technology, in which cultural activities are harmonized with the rhythm of climate and hydrology management.

CHAPTER EIGHT

CAPTURING WATER IN DRYLAND ENVIRONMENTS

OVER the centuries, various forms of capturing water for agriculture have been developed. Water harvesting is particularly important in dryland agriculture. Some of the very earliest forms of agriculture in the Middle East were based on techniques such as diversion of *wadi*[2] flow onto agricultural fields. Floodwater harvesting has been practised in the desert areas of Arizona and northwest New Mexico for at least the last 1,000 years (FAO 1991). In Africa, South Asia and in other parts of the world, traditional societies have developed a diversity of local water harvesting and management regimes that still continue to survive (Agarwal and Narain 1997). In India alone, more than 35 traditional rainwater harvesting systems were documented and are still in practice.

Semiarid regions are characterized by low erratic rainfall, poor nutrient soils and high temperatures, which pose serious constraints on crop productivity especially when water supply is inadequate. Semiarid areas have at least one entirely rainless month per year and the amount of rainfall ranges from 500-

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[2] *Wadi* is traditionally a valley. In some cases it can refer to a dry riverbed that contains water only during times of heavy rain. *Wadis* tend to be associated with centres of human population because sub-surface water is sometimes available in them. Nomadic and pastoral desert peoples will rely on seasonal vegetation found in *wadis*, even in regions as dry as the Sahara.

1,000 mm per annum in most areas. This means that conditions of water deficit, water stress or drought are common in these areas, and in many regions the situation is even more dramatic due to climate change. Extreme drought stress leads to poor crop yields and also contributes to land degradation and desertification (Barrow 1999). This process has become evident in the Sahel region (West Africa) where rainfall levels have declined by 20-40 percent in recent decades accompanied by severe land degradation.

In sub-Saharan Africa, 40 percent of the farmland is located in semiarid and dry sub-humid savannahs. Despite the frequent occurrence of water scarcity, in most years there is more than enough water to potentially produce crops. The problem is that large volumes of water are lost through surface runoff, soil evaporation and deep percolation. The challenge is how to capture that water and make it available to crops during times of scarcity (Reij et al. 1996). Although the amount of rainfall that can be effectively utilized for crop growth in these lands is low, many farmers have created innovative water harvesting systems that take advantage of the limited rainfall.

Some examples of traditional water harvesting systems are provided below.

a) Traditional water harvesting systems in India

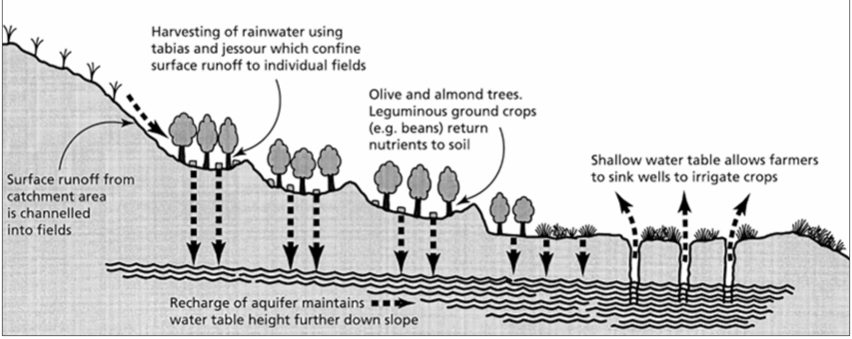
Southern Asia is known for its traditional water harvesting systems and techniques. They have a history of continuous practice for over 8,000 years and are still functional. In India alone, there are over 35 traditional rainwater harvesting systems. These systems have been pivotal to the emergence and diversification of food production. Many of these rainwater harvesting systems require scooping of the earth and putting up embankments or erecting elongated soil heaps along farm boundaries. The earliest examples of these rainwater harvesting systems include the havelis of Jabalpur, bandh and bandhulia of Satna, virda of Gujarat, ahar-pynes of Bijar, eri of Tamil Nadu, dhora of Aravalis, and khadins of Rajasthan. Khadin, which is also called a *dhora*, is an ingenious construction designed to harvest surface runoff water for agricultural production. The main feature of this system is a very long (100-300 m) earthen embankment built across the lower hill slopes lying below gravelly uplands. Sluices and spillways allow excess water to drain off. The system is based on the principle of harvesting rainwater on farmland and subsequent use of this water-saturated land for crop production. It was designed by the Paliwal Brahmins of Jaisalmer, western Rajasthan in the 15th century, and it has great similarity with the irrigation methods of the people of Ur (present Iraq) in around 4500 BC and later of the Nabateans in the Middle East. A similar system is also reported to have been practised 4,000 years ago in the Negev desert, and by the Hopi Indians in Colorado Plateau 500 years ago (Pandey et al. 2003; http://www.rainwaterharvesting.org).

b) Rainwater harvesting system in southern Tunisia

In southern Tunisia, as in most semiarid ecosystems, crops have historically been at risk from physiological drought and so rainwater must be collected, concentrated and transferred to cropped areas quickly to minimize losses via evaporation and runoff. Such macro-catchment rainwater harvesting has a long history in the Matmata Plateau (Hill and Woodland 2003). The majority of rain falls as high-intensity, low-frequency downpours. Overland flow is generated rapidly and it travels quickly over the steep slopes, supplying water and soil to valley bottoms. Earthen check dams (*tabias* – strengthened by dry stone retaining walls) are sited progressively downslope to arrest material eroded from the valley sides and this sediment is levelled to form agricultural fields (*jessour*). Water that is trapped behind these dams after rains infiltrates into the soil and it can create a local, albeit temporary, phreatic water supply (Figure 1). The rainfall multiplier effect of rainwater harvesting depends primarily on the ratio of catchment area to cropped area. This ratio is typically between 2:1 and 10:1 in southern Tunisian macro-catchments. To the west of Matmata, a ratio of 6:1 translates into field sizes approximating 0.6 ha and catchment sizes of around 4 ha, varying slightly with site, topography and capability of the builders. If infiltration and evaporation losses are prevented, 10 mm of rain falling on a 1 ha semiarid catchment can yield around 100,000 litres of water.

Today most farmers in Matmata practise agroforestry on the *jessour* using these methods. In 3 ha fields they are able to grow relatively demanding trees such as olives, figs, almonds, pomegranates and date palms. Annual crops include barley, peas, lentils and beans, and fodder crops such as alfalfa. These parcels are often dispersed following the natural occurrence of water in the landscape, so fragmentation of holdings is a common feature.

Figure 1. Traditional water harvesting in agroecosystems of Tunisia (Hill and Woodland 2003)



Rainwater harvesting in the region remains largely decentralized in nature. Sites are managed on a collective and community basis following local custom and enforced by Islamic law. Under such systems, water is considered as communal property, with just enough consumed to meet community needs without wastage. Local expertise is anchored in an awareness of the reciprocal relationship between surface water and groundwater. Almost all farmers are aware of the necessity of replenishing what they termed loosely as underground water supplies in order to ensure water for community use in future seasons. Rainwater harvesting on hillsides helps to increase infiltration and hence recharge groundwater, which is drawn upon locally and in the lower catchments. Land units are integrated effectively with respect to hydrology, allowing equitable use of water over space and, crucially, replenishing long-term stores (Hill and Woodland 2003).

Vernacular knowledge and craftsmanship, derived from centuries of interaction with the local environment, has been used to equip *tabias* with different types of overflow. These promote effective water distribution and allow some flexibility against climatic extremes. Lateral overflows are employed in 60 percent of *tabias* in the Matmata Hills. These are purpose-made breaches in the earthen bunds at valley sides. Simple lateral overflows are carved out of the soil, their earthen floors resting at the same height as the up-slope terrace. They permit excess water to flow by gravity onto the terrace below, ensuring irrigation water with minimal erosive capability. Erosion of the overflows themselves is often reduced by strengthening their floors and sides with stones. Central overflows have been observed within 38 percent of *tabias* in the Matmata Hills. These require greater manpower and more materials to construct when compared with lateral overflows. Dry stone or cement walls retain the earth of the *tabia* and the overflow floor is stepped downslope to dissipate the energy of escaping water (Reij et al. 1996).

The height of *tabia* overflows ensures that cropped fields downslope are not deprived of water by higher fields. Equally, the height of the overflow prevents the buildup of too much water after storms such that the root zone remains waterlogged for long periods. This enhances agricultural potential by increasing root aeration and reducing soil salinization because water infiltrates efficiently and is used rapidly by crops. The water table resides at depth, ensuring that salts are not brought to the surface by water table rise. Appropriate *tabia* construction reduces the likelihood of breaching and soils being washed downslope by headward erosion.

c) Qanat *(*karez *or* foggara*) irrigation systems*

In Iran, *qanat* (*karez* or *foggara*) irrigation systems are ancient (ca. 800 BC) and consist of underground tunnels constructed into a cliff, scarp or base of a mountainous area, following an aquifer, or from rivers, to bring water out to the surface. The tunnels are straight and horizontal with a slope to allow the water to drain out into an oasis or irrigation system. *Qanats* are important in arid zones where water is scarce and minimize evaporation loss. They provide 80 percent of the water around the central plateau of Iran (e.g., Husseinieh, Isfahan), and also occur in Sinkiang, western China (e.g., Turfan oasis), southwest Afghanistan, southwest Turkmenistan, the Arab world, Libya (e.g., Zella), Tunisia, Algeria (e.g., Germa), and Morocco. They were introduced by the Romans into Egypt and Syria, and into southern Spain by the Moors. The volume of water produced depends on the type and extent of the aquifer, and its recharge rate. When tunnelling horizontally, air shafts 50-180 ft deep are constructed every 50-150 ft to remove the mined soil, clean the tunnels of silt, and aerate the tunnels. One of these shafts is a mother well (*madaarchah*). While the men and boys construct and clean the *qanats*, a suitable female (e.g., widow, older woman, virgin) volunteers to be the “bride” of the *qanat* to ensure adequate water supply, and has to be faithful to the *qanat* for a season (or a year) by bathing ritually in the *qanat* during the warmer months. Farmers donate part of their crop (usually 1 bushel of wheat) to the “bride” after harvest. *Qanats* are owned communally, and their water is distributed on a rotational basis (*madaar*) over a period (10-14 days) to community members. *Qanats* irrigate cereal crops (barley, wheat) in autumn and other crops (e.g., sugar beet, tobacco, melons, turnips, onions and pomegranate) in spring, with land being left fallow every third year.

d) The qhutañas *in Bolivia*

Aymaran indigenous peoples of Bolivia have been coping with water insecurity and scarcity over centuries. In order to collect rainwater in the mountains and pampas they have developed a sophisticated system of rainwater harvesting by way of constructing small dams called *qhutañas*. This traditional technique of rainwater harvesting has proved to be vital not only to people but also to livestock in times of droughts. Additionally, it has been found that these water reservoirs serve as thermoregulators of humidity and help reduce the risk of skin cancer as they diffuse sun rays (UNFCCC 2007).

e) Floodwater farming in semiarid North America

In the semiarid zones of North America, in which water is the principal limiting factor, the experiences of the Seri, Pima, Papago and other indigenous groups offer local options for rainfed agriculture. These cultures have made resources of a multitude of desert species with high nutritive content that can form the basis for agriculture appropriate to these zones. Some of them have developed agricultural techniques which utilize floodwater on a small scale, with hand-made canals, terraces, berms and diversions for the retention and utilization of rainwater (Nabhan 1979).

Floodwater farming (also called floodwater harvesting) is the management of sporadic flashfloods for crop production. It is an ancient technique in the southwestern regions of North America that is currently being re-evaluated. Agronomically productive conditions have been developed by geomorphological alterations of the floodplain, including canals, terraces, grids, spreaders, and weirs. These environmental modifications serve to concentrate the runoff from a large watershed into a strategically located field, and break the erosive force of the incoming water. In addition, native Americans manipulate the wild and weedy flora of floodwater fields by discouraging or protecting and harvesting selected species (Nabhan 1979). In Arizona, the Papago and other native cultures of the Sonoran Desert historically sought alluvial fans (low valleys where floodwaters and the organic matter they carry concentrate) for establishing productive fields producing crops adapted to the semiarid conditions such as coyote gourd, desert amaranthus, tepary beans, devil's claw and a variety of succulents, cacti and herbaceous perennials.

Living in a Sonoran Desert area of 150-350 mm mean annual rainfall, the Papago have traditionally irrigated their floodplain fields with the stormwaters of intermittent water courses, or *arroyos* (Nabhan 1982). In the desert, there are usually no more than 3-15 substantial storm events during the year; of these, typically no more than 5-6 are sufficiently large to stimulate a spurt of plant production.

In one Papago community, 100 families maintained 355 hectares of crops on farms receiving stormwater, organic matter and nutrients from 240 kilometres of watershed. With a single intense storm, enough nitrogen-rich litter from leguminous trees, rodent faeces and other decomposed detritus from the uplands are shed onto the alluvial fans to add as much as 30 cubic metres of organic material to each hectare (Nabhan 1979; Nabhan et al. 1981). In addition to 50-day maize, the tepary bean (*Phaseolus acutifolius var. latifolius*) is the most nutritionally important crop for the Papago Indians. Teparies are a heat- and drought-adapted crop of the Papago, and historically the most important protein and mineral source (Nabhan et al. 1981). Their mean protein contents and seed yields per plant tend to be higher in Papago flashflood fields than in modern irrigated counterparts. Unfortunately, traditional Papago Indian floodwater farming today is a threatened agricultural ecosystem.

The traditional Papago agricultural system presents a different food production strategy than most groundwater-based systems introduced into arid lands. Responding to sparse, irregular water availability in the desert, the Papago produce crops (principally tepary beans, corn, squashes and others) which grow quickly enough to avoid mortality due to prolonged drought. They deal with the uneven spatial distribution of stormwaters by concentrating into small fields and utilizing several fields, each spatially separated from the others. Within each field, mixed plantings occur with wide spaces between plants, a risk-minimizing tactic. In general, Papago farming families have seldom been willing to “force” a single field to produce more through intensifying manipulation or by concentrating their efforts on a single plant resource. The Papago strategy seeks more dependable seed yield for the water available, but not necessarily per unit of land. Since water, not land, is the limiting factor in the deserts, this strategy has adaptive value (Nabhan 1982).

f) The bordos *of Mexico's Mezquital Valley*

The Mezquital Valley, which is part of the Central Mexican Highlands, has been inhabited by people of the Otomí or Hñähñü ethnic group since at least the pre-Columbian period. They established permanent settlements based on rain-fed agriculture and sometimes even built water-catching structures (Toledo et al. 1985).

The experience of the Otomí in this area, which is one of the poorest and most marginalized regions of Mexico, shows how people can survive using unusual food sources. The Mezquital Valley exhibits several limiting ecological conditions, especially its infertile calcareous soils and scarcity of water. This environment conditioned the relationships between the Otomí and its surrounding landscapes, especially in the perception and use of habitats, water resources, soils and plant species.

According to the studies of Johnson (1977), the natural resource management practised by the Otomí people reflects a level of diversified production adapted to the different landscapes of the Mezquital Valley as well as an emphasis on rainy-season agriculture and the intensive use of maguey (*Agave* spp.). Maguey species are used to produce fibre for making cordage and clothing, cooked flesh and especially pulque, a mildly alcoholic beverage formed by the natural fermentation of the sugary sap that these plants produce (Parsons and Parsons 1990). In addition, maguey species are also used as key plants in the management of soils during the construction of terraces to avoid erosion.

The Otomí people distinguish three classes of landscape units: the cerro, the lowland and the hill. The cerro, which is normally communal land, is covered with wild vegetation (shrublands) used to feed animals and for hunting and gathering. People also use the lowest portions of the cerro to build houses. Most of the agricultural fields are on the hills and lowlands. For cultivation, Otomí farmers recognize three types of hills – gullies (*barrancas*), slopes (*laderas*) and flatlands (planes) – and two classes of lowlands (gullies and flatlands). During the wet season, water washes away soil from the slopes and gullies of the hills to the lowlands, to deposit it on the low flatlands. Thus, lowlands are the areas to which all water flows and where sediments accumulate (Johnson 1982).

With a detailed knowledge of soils, relief, vegetation and water movements, the Otomí people build *bordos* to trap rainwater and build up the soil with the sediments it brings. The best place for a *bordo* is right in the path of the water that is the gully itself. This kind of bordo is called *atajadizo*. Farmers also build *bordos* on the hillside. It takes six or seven rainstorms to get a crop (generally maize and beans) on hillside *bordos* and *atajadizos*. They normally are placed along the contours in order to take best advantage of the water flow. The placement of stones and plants of maguey is crucial during the construction of *bordos*, and fields are recurrently fertilized with manures to improve the soil. Organic fertilizers consist of mixtures of goat, sheep and cow manures, household trash, ashes, dry plants and soils from other terrain (Johnson 1977).

CHAPTER NINE

FARMERS' INNOVATION AND LOCAL APPROACHES IN CLIMATICALLY MARGINAL ENVIRONMENTS

FARMERS are the key actors and players with responsibility for improving land and as land managers; their needs, priorities, resources and preferences are highly diverse. They have a wealth of knowledge about their crops, soils, farming environment, and economic condition.

Many of the traditional agricultural knowledge systems described above and the ways farmers adapt and cope with the changing environment and socioeconomic conditions have proved invaluable to local organizations assisting poor farmers in several regions in restoring the ecological integrity of micro-watersheds and the productive capacities of smallholder/traditional family farming communities. Many initiatives led by farmers' organizations and by non-governmental organizations (NGOs) emphasizing reforestation, soil conservation and efficient water harvesting and use of rainwater represent successful examples of key strategies to improve rural livelihoods in marginal environments. Below are some of the examples of farmers' innovation in sustaining local livelihoods and dealing with climatically marginal environments.

a) Farmers in Burkina Faso and Mali

In many parts of Burkina Faso and Mali there has been a revival of the old water harvesting system known as *zai*. The *zai* are pits that farmers dig in rock-hard barren land, into which water otherwise could not penetrate. The pits are about 20-30 cm deep and are filled with organic matter. This attracts termites which dig channels and thus improve soil structure so that more water can infiltrate and be held in the soil. By digesting the organic matter, the termites make nutrients more easily available to plants. In most cases farmers grow millet or sorghum or both in the *zai*. At times they sow trees directly together with the cereals in the same *zai*. At harvest, farmers cut the stalks off at a height of about 50-75 cm, which protects the young trees from grazing animals. Farmers use anywhere from 9,000 to 18,000 pits per hectare, with compost applications ranging from 5.6 to 11 t/ha (Reij and Waters-Bayer 2001).

Over the years, thousands of farmers in the Yatenga region of Burkina Faso have used this locally improved technique to reclaim hundreds of hectares of degraded lands. Many farmers have been exposed to the improved *zai* techniques particularly after the establishment of the *zai* school model in the village of Somyanga.[3]

Farmers have become increasingly interested in the *zai* as they observe that the pits efficiently collect and concentrate runoff water and function with small quantities of manure and compost. The practice of *zai* allows farmers to expand their resource base and to increase household security. Yields obtained on fields managed with *zai* are consistently higher (ranging from 870 to 1,590 kg/ha) than those obtained on fields without *zai* (average 500-800 kg/ha). Many farmers in the Dogon Plateau of Mali, a region where extreme drought periods with temperatures in excess of 40°C and evaporation rates of 250 mm/month

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[3] Established by Mr Ousseni Zorome.

alternate with heavy and destructive rains, have reported similar benefits from the adoption of *zai*.

b) Farmers in Zimbabwe

In Zimbabwe hundreds of dryland farmers have benefited from the water harvesting systems developed by one farmer, Mr. Phiri Maseko. Phiri's three-hectare plot is located on the slope of a hill, immediately below which is the homestead. One of the most important resources is a large granite dome (*ruware*) above the plot. In an uncontrolled situation this rock could cause severe erosion by channelling a lot of water onto the farm below. Instead, the rock provides the main source of water for the trees, crops and household. Tiers of stonewall terraces catch and direct the flow of water so that it can sink into the soil and replenish the underground store. The terraces trap the grass seeds and create swathes of protective vegetation. Silt traps ensure that the terraces do not get choked with sand. Most of the water is then channelled into a seasonal unsealed reservoir to encourage efficient infiltration of water into the soil rather than storing it on the surface. Some of the water can be siphoned into a storage tank made from bricks and plaster (Reij et al. 1996).

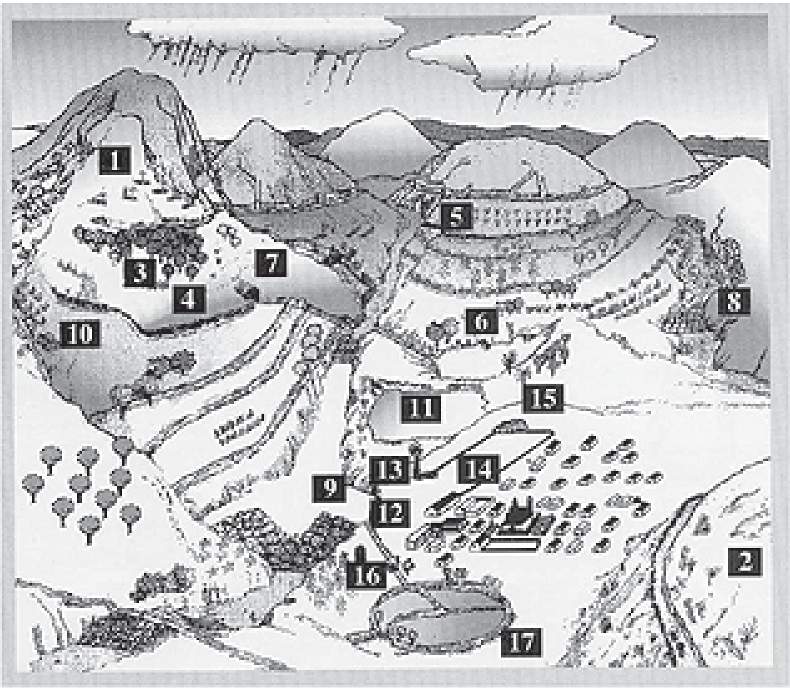
c) Farmers in Mexico

In the Mixteca region of Mexico, a mountainous area with limited rainfall and very eroded soils, the Centro de Desarrollo Integral Campesino de la Mixteca (CEDICAM) has since 1989 organized hundreds of farmers in nine rural communities to reforest large areas and to build contour ditches on hillsides above threatened springs and shallow wells to recharge the aquifers that feed these drinking water sources. The groups have built kilometres of ditches for soil conservation and have reforested hundreds of hectares with pines (*Pinus oaxacana*) and some native species. In El Progreso, about 80 percent of the entire community participate and have restored 100 hectares of degraded land. In Buenavista Tilantongo, the community reforested 10 hectares. In El Carmen, farmers started reforesting 11 years ago, planting 40,000 trees in 2003 and 70,000 in 2004. It is estimated that one lineal metre, 60 cm x 60 cm ditch can capture up to 360 litres of water from one rainfall event. A long 100 m ditch can potentially capture 36,000 litres, which ideally would infiltrate deep into the soil and thus recharge the aquifers (Altieri et al. 2006). The strategy is similar to that promoted by the Water Forever project of Alternativas y Procesos de Participación Social, A.C. (Social Participation Alternatives and Processes) directed at the ecological restoration of the watershed with a number of techniques to effectively harvest water and conserve soils for sustainable production (Toledo and Solis 2001; Figure 2).

Under CEDICAM's guidance, local farmers have:

- made efficient use of rainwater and increased water supplies and spring flows as the new contour ditches now catch about 80 percent of the rain. Cisterns that catch rooftop rain have been built in several households and each can catch up to 15,000 litres of water, providing each household up to six times the water they usually consume in the dry periods.
- planted over a million native trees in the past five years
- saved and improved native corn varieties and learned to produce organic fertilizers (including vermicompost) using local waste and biomass
- diversified plant production by re-adopting the traditional polyculture of corn, beans and squash. Local farmers are producing more total food per hectare than when they

Figure 2. Harvesting water through watershed regeneration in the Mixteca region, Mexico



To regenerate the Mixteca region's basins, specific treatments are applied on the hills, knolls, valleys and ravines using different technologies. The work begins on the hills with retaining devices that include ditches and trenches (1), water harvesting ring (2), reforestation (3) and contour lines with vegetation (4). On the rises where the slopes are less steep than on the hills, borders, terraces (5), earthen dikes (17) and watering holes (6) can be built, making it possible to water cattle and other animals or irrigate crops. If we take into account that ravines have been formed where water has most easily eroded the soil, it can be regenerated by building rock seeping dams (7) or gabion seeping dams (8). These works slow the speed and force of the initial flow with provisional water stagnation and soil retention, thus achieving control over the two natural resources involved, soil and water. The water obtained from building dams can be utilized by building shallow wells (16), seeping galleries and diversion dams (9) that channel part of the flow of water to agricultural land. In addition, the water in the high parts of the basins replenishes existing springs (10). Once water has been gathered, irrigation systems (11) are designed as well as water storage systems that prevent its filtering and evaporating and make it available for distribution to the communities. The water can be transported to where it is used by earth-filled canals (12), unlined or lined with cement or stone. Nevertheless, the transportation of piped water (14) is the most efficient way to avoid both filtration and evaporation. Before laying the pipes, it is necessary to construct a tank (15) where the different particles in the water will settle to avoid clogging. For this work, operating costs can be cut by using alternative energy, like windmills (13) or manual pumps that will finally distribute the water to the population. (Toledo and Solis 2001)

mono-cropped corn; thus, improvements in family nutrition, soil fertility and family income are noticeable in some communities.

d) Farmers in Brazil

The Sertao region of Northeastern Brazil is undergoing a process of desertification due to the massive expansion of soybean monocultures, which, together with the growing climate instability, is provoking a situation of social and economic instability, forcing millions of the dryland inhabitants to migrate to urban centres. With the assistance of the Instituto de Permacultura Cerrado, farmers have engaged in the testing and adoption of crop combinations comprising drought-hardy forage plants which guarantee some production even in El Niño years (such as *Opuntia* cactus); leguminous trees such as *Gliricidia, Leucaena* and *Canavalia* plants to fix nitrogen and produce biomass, and pigeon pea (*Cajanus cajan*) which also produces beans for food; short-term cash crops (radishes, sesame) and castor bean (the main cash crop, resistant to drought); a few rows of corn; and cowpeas filling in the rest of the space. Monitoring of the performance of these polycultures is showing that from the same field, even in low-rainfall years, farmers harvest some vegetables, corn, beans and cowpeas, sesame, pigeon pea, and (as the trees mature) fruits, wood and fodder, while having castor bean for sale and fodder for their animals (http://www.tortuga.com/permacultura/English/polycultures.htm). Similar results have been obtained by farmers working in close association with the Instituto de Permacultura da Bahia through their project Policultura No SemiArido, which promotes polycultures in drylands of western Bahia combining biomass-producing plants with food crops, impacting 748 families in various municipalities (http://www.permacultura-bahia.org.br/aconteces.asp?cod=64).

CHAPTER TEN

SUMMARY AND CONCLUSIONS

THE world is now facing a new era of climate change and the impacts of climate change are already being felt everywhere, particularly in the developing countries and small islands. The local knowledge systems and agricultural practices and techniques adopted by local people remain the dominant form of coping mechanisms/responses to climate change. However, there is concern that the escalating global effects of climate change could increase food insecurity due to the myriad interactions between climate variability and food systems, of which little is known. Undoubtedly, the livelihoods of thousands of smallholder/traditional family farming communities and indigenous peoples in the developing world will be severely impacted by climatic changes. It is therefore critical that implications of climate change for food security are explored and understood not only at global and national levels but also at local level. It is also imperative to have a better understanding on how to sustain and combine indigenous agricultural knowledge systems and scientific knowledge, and how to translate this into decision-making processes that provide the necessary support to the local peoples. Lessons from the past show that thousands of traditional farmers in many rural areas have evolved and adapted to ever-changing environments by developing diverse and resilient farming systems in response to different opportunities and constraints faced over time. Many of these agricultural systems around the world serve as models of sustainability that offer examples of adaptation measures that can help millions of rural people to reduce their vulnerability to the impact of climate change and to maintain ecosystem goods and services.

Some of these adaptation strategies include:

- use of locally adapted varieties/species exhibiting more appropriate thermal time and vernalization requirements and/or with increased resistance to heat shock and drought;
- enhancing organic content of soils through compost, green manures, cover crops, etc., thus increasing water holding capacity;
- wider use of local knowledge and practical means to “harvest” water and conserve soil moisture (e.g., crop residue retention and mulching), and more effective use of irrigation water;
- managing water to prevent waterlogging, erosion, and nutrient leaching where rainfall increases;
- use of crop diversification strategies (intercropping, agroforestry, crop-sequencing, etc.) and integration with other farming activities such as livestock raising;
- preventing pest, disease, and weed infestations via management practices that enhance biological and other natural regulation mechanisms (antagonisms, allelopathy, etc.), and development and use of varieties and species resistant to pests and diseases; and
- using climate forecasting to reduce production risk.

The challenge now is how to rapidly mobilize this knowledge so that it can be applied to restore already affected areas or to prepare rural areas predicted to be hit by climate change. For this horizontal transfer to occur quickly, emphasis must be given to involving farmers directly in the extension of innovations through well-organized farmer-to-farmer networks. The focus should be on strengthening local research and problem-solving capacities. Organizing local people around projects to enhance agricultural resiliency to climate change must make effective use of traditional skills and knowledge, as this provides a launching pad for additional learning and organizing, thus improving prospects for community empowerment and self-reliant development in the face of climatic variability.

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