DIDACTIC TOOLKIT FOR THE DESIGN, MANAGEMENT AND ASSESSMENT OF RESILIENT FARMING SYSTEMS

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Red Iberoamericana de Agroecología Para el Desarrollo de Sistemas Agrícolas Resilientes al Cambio Climático

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WHAT IS THIS DIDACTIC TOOLKIT FOR?

The main objective of this methodological toolkit is to aid farmers and technicians to better understand the principles and/or mechanisms that underlie the resiliency (or lack thereof) of farming systems and how agroecological management can enhance the capacity of farmers to adapt to unpredictable and severe climatic variability.

The tool allows users to better clarify their perceptions of climate change, use indicators to assess the vulnerability of their farms and improve their ecological resiliency via agroecological interventions that enhance the adaptive response capacity of farmers.

The toolkit can be used for:

a. Conducting a rapid agroecological assessment of farms and their level of vulnerability
b. Initiating a process of agroecological conversion to enhance the response capacity of farmers and thus improve the resiliency of their farming systems
c. Monitoring the trajectory of the farms under agroecological conversion after climatic events such as hurricanes, rain storms and/or drought.

SOME BASIC PRINCIPLES AND CONCEPTS

What Are Vulnerability And Resiliency?

Resilience is defined as the ability of a farming system to absorb disturbances and adapt to stress and change while retaining its productive structure and ability to yield. Thus, a "resilient" agroecosystem would be capable of providing food production when challenged by severe drought or by excess rainfall. Conversely, vulnerability can be defined as the possibility of loss of biodiversity, soil, water or productivity by an agroecosystem when confronted with an external perturbation or shock. Vulnerability refers to the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate variability and denotes a state of susceptibility to harm from exposure to stresses associated with environmental change due to the absence of capacity to adapt (Folke 2006).

When exposed to climate change, the resulting risk endured by a farm is the product between threat, vulnerability and response capacity, as described in Altieri *et al.* (2015):

$$\textbf{Risk} = \frac{\textbf{Vulnerability * Threat}}{\textbf{Response Capacity}}$$

Risk is understood as any natural phenomenon (drought, hurricane, flood, etc.) that signifies a change in the environment inhabited by a rural community.

Vulnerability is determined by the biophysical features of the farm and the socio-economic conditions of farmers that enhance or reduce the exposure to the threat.

Threat is the climatic event's intensity, frequency, duration and level of impact (i.e., yield losses due to storm or drought)

Response capacity is the ability (or lack thereof) of the farming systems and the farmers to resist and recover from the threat depending on the level of social organization and the agroecological features (e.g., crop diversity) of the farms.

In summary, for an event to be considered a risk depends on whether in a particular region there is a community that is vulnerable to it. In order for the event to become a threat, there should be a high probability that it will occur in that region, and for the threat to be devastating will depend on the magnitude of the event and the level of vulnerability of the community. Such vulnerability can be reduced by the response capacity determined by the agroecological features of the farms and the management strategies used by farmers to reduce climatic risks and to resist and recover from such events. Therefore adaptation refers to the adjustments made by farmers to reduce risks. The capacity of farmers to adapt is based on the individual or collective reserves of human and social capital that include attributes such as traditional knowledge and skills, levels of social organization and safety networks, etc. As observed in Figure 1, the level of vulnerability of a farm is determined by its type of agroecological infrastructure (level of landscape, crop and genetic diversity, soil quality and cover, etc.) and social traits of the family or community (levels of organization and networking, food self-sufficiency, etc.). The vulnerability can be reduced by the capacity of response of the farmers and their farms, which in turn determines their ability to resist events and recover function and infrastructure.

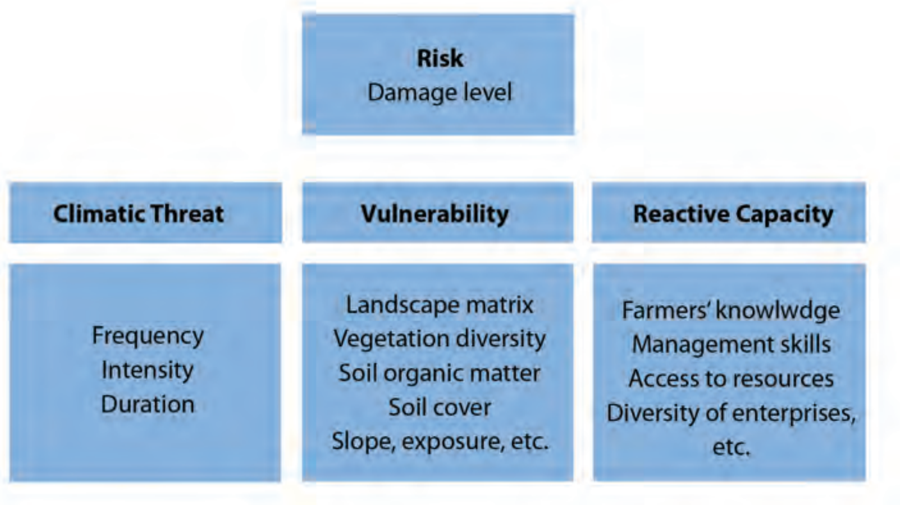


Figure 1. Socio-ecological features that determine the vulnerability and reactive capacity of farmers to enhance the resiliency of their systems and communities to climatic variability

What Do We Know About Farms That Are Resilient?

There is increasing scientific evidence suggesting that diversified farming systems such as agroforestry, silvopastoral and polycultural systems comprise complex agroecosystems which are able to adapt and resist the effects of climate change. Agroforestry farms exhibiting high degrees of plant diversity have been shown to buffer crops from large fluctuations in temperature, thereby keeping the crop closer to its optimum conditions. Shaded coffee systems have been shown to protect crops from decreasing precipitation and reduced soil water availability because the overstory tree cover is able to reduce soil evaporation and increase soil water infiltration (Lin 2007).

Intercropping enables farmers to produce various crops simultaneously and minimize risk (Vandermeer 1989). 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 and peanut, millet and peanut, and sorghum and millet. All the intercrops over-yielded consistently at five levels of

The milpa (corn-beans) in MesoAmerica exhibits yield stability in the midst of climatic variability.

moisture availability, ranging from 297 to 584 mm of water applied over the cropping season. Quite interestingly, the rate of over-yielding actually increased with water stress, such that the relative differences in productivity between monocultures and polycultures became more accentuated as stress increased (Natarajan and Willey 1986).

Intensive silvopastoral systems (ISS) are a sustainable form of agroforestry for livestock production that combines fodder shrubs planted at high densities, trees and palms, and improved pastures. High stocking and the natural production of milk and meat in these systems are achieved through rotational grazing with electric fencing and a permanent supply of water for the cattle. In the "El Hatico" farm located in the Valle del Cauca, Colombia, a five-story ISS composed of a layer of grasses, *leucaena* shrubs, medium-sized trees and a canopy of large trees has over the last 18 years increased stocking rates to 4.3 dairy cows per hectare and milk production by 130%, and completely eliminated the use of chemical fertilizers. 2009 was the driest year in El Hatico's 40-year record, with precipitation having dropped by 44% compared to the historical average. Despite a reduction of 25% in pasture biomass, the fodder production of trees and shrubs remained constant throughout the year, neutralizing the negative effects of drought on the whole system. In response to the extreme weather, the farm had to adjust its stocking rates and increase energy supplementation. In spite of this, the farm's milk production for 2009 was the highest on record, with a surprising 10% increase compared to the previous four years. Meanwhile, farmers in other parts of the country reported severe animal weight loss and high mortality rates due to starvation and thirst. The productive performance of El Hatico during the exceptionally hot and dry period of El Nino Southern Oscillation illustrates the huge potential of ISS as a sustainable intensification strategy for climate change adaptation and mitigation (Murgueitio *et al.* 2011). The combined benefits of water regulation, favorable microclimate, biodiversity, and carbon stocks in the above-described diversified farming systems provide not only environmental goods and services for producers but also greater resilience to climate change.

How Does Biodiversity Help To Enhance Farm Resiliency?

In any farm the level of existing biodiversity can make the difference between the system being stressed or resilient when confronting a biotic or abiotic perturbation. In all agroecosystems a diversity of organisms is required for ecosystem function and to provide environmental services (Altieri and Nicholls 2004). When agroecosystems are simplified, whole functional groups of species are removed, shifting the balance of the system from a desired to a less desired state, and affecting their capacity to respond to changes and to generate ecosystem services (Folke 2006). Two categories of diversity can be distinguished in agroecosytems: functional

Colombian intensive silvopastoral systems with an overstory of trees and shrubs are more resilient than monoculture pastures, allowing for continual fodder availability for cows, which in turn maintain a stable level of milk production despite low rainfall.

and response diversity. Functional diversity refers to the variety of organisms and the ecosystem services they provide for the system to continue performing (Loreau *et al*. 2001). Response diversity is the diversity of responses to environmental change among species that contribute to the same ecosystem function. An agroecosystem that contains a high degree of response diversity will be more resilient against various types and degrees of shocks (Cabell and Oelofse 2012). Swiderska *et al.* (2011) found that maintenance of diverse traditional crop varieties (maize, potatoes, rice) was essential for adaptation and survival by poor farmers in China, Bolivia and Kenya. Even when planted alongside modern crops, traditional crop varieties are still conserved, providing a contingency when conditions are not favorable.

WHAT TYPES OF AGROECOLOGICAL PRACTICES ENHANCE RESILIENCY?

Enhancing Resilience At The Landscape Level

In agroecology the diversification of farming systems is an important resilience strategy for farmers. Diversification of agricultural systems can occur in many forms (genetic variety, species, structural) and scales (within-crop, within-field, and at the landscape level), giving farmers a wide variety of options and combinations for the implementation of this strategy. At a landscape level, diversification may occur by integrating multiple production systems such as mixing agroforestry management with cropping, livestock, and fallow with patches of natural vegetation to create a highly diverse piece of agricultural landscape.

Small crop fields inserted in a complex landscape tend to exhibit higher resiliency than large fields surrounded by cleared land which promote the simplification of agricultural landscapes containing only small fragments of natural habitats. Maintaining a complex matrix of field margins, riparian buffers, and forest edges around farms can yield several ecological services for farmers. For example, forest fragments adjacent to agricultural land uses increase and stabilize pollination and biocontrol services by harboring beneficial insects (Bianchi *et al.* 2006). Agricultural nutrients and sediment can be managed with soil conservation practices to protect downstream fisheries.

There is accumulating evidence that the expansion of agriculture at the expense of natural habitats, in combination with high agrochemical inputs in crop fields, are the primary causes for the rapid decrease of biodiversity in many of these landscapes. Concerns have arisen about the deterioration of ecosystem functions in simplified landscapes as a result of the loss of biodiversity (Harvey *et al*. 2014). Box 1 provides a list of practices that should be avoided as they reduce biodiversity and resiliency at the landscape level. However, appropriate agroecological management can restore such functions by ameliorating many of the negative environmental impacts of agriculture, while maintaining key components of biodiversity and thus ensuring provisioning of ecological services.

Key practices that confer adaptation features at the landscape level include (Tscharntke *et al.* 2005):

- Maintenance of landscape diversity — including a mosaic of agricultural and natural habitat.
- Conservation and restoration of riparian areas within the agricultural landscape.
- Conservation and restoration of remaining forest habitat in the surrounding landscape — including formal and informal protected areas.
- Establishment of agroforestry and silvopastoral systems.
- Increasing the duration of fallow periods.
- Restoration of degraded or fragile lands.
- Restoration and conservation of wetlands.
- Reduced expansion of cropland into remaining natural habitats.
- Maintenance of habitat connectivity to ensure pollination and pest control.

Keeping landscapes with a high level of diversity including different types of land cover, various forms of land use, and species and varietal diversity of plants and animals performs several climate adaptation functions: (1) reduces risks of production and livelihood losses from erratic and harsh climatic conditions; (2) allows strategic utilization of areas of the landscape for emergency food, feed, fuel, and income reserves.

Box 1. Landscape intensification practices that reduce agrobiodiversity and resiliency (Tscharntke *et al.* 2005)

Farmers specializing in one or few (arable) crops instead of mixed farming

Converting perennial habitat (grassland) to arable fields

Destroying edge habitats (hedges, field boundaries, buffer zones along creeks)

Reallocating land to increase field size and make farms more compact

Simplifying landscapes with a spatially and temporally limited number of land-use types increasing landscape homogeneity

Giving up traditional, low-intensity land-use management

Avoiding set-aside fallows and cultivating formerly abandoned areas (old fields, fallows)

Lowering landscape-wide water tables

Fragmenting natural habitat

A peasant farming system in Colombia inserted in a complex landscape matrix.

Increasing Plant Diversity In Farms

For decades agroecologists have contended that a key strategy in designing a sustainable agriculture is to reincorporate diversity into the agricultural fields and surrounding landscapes and manage it more effectively (Altieri and Nicholls 2004). Diversification occurs in many forms: genetic variety (crop variety mixtures) and species diversity at the temporal level such as in rotations or at the spatial level as in intercropping systems, and over different scales within field and landscape as in the case of agroforestry, crop-livestock integration, hedgerows, corridors, etc. Emergent ecological properties develop in diversified agroecosystems that allow the system to function in ways that maintain soil fertility, crop production, and pest regulation. The same agroecological management practices that increase agroecosystem diversity and complexity as the foundation for soil quality, plant health and crop productivity also increase farm resiliency.

Given the positive role of biodiversity in providing stability to agroecosystems, many researchers have argued that enhancing crop diversity will be even more important in a future exhibiting dramatic climatic swings. Greater agroecosystem diversity may buffer against shifting rainfall and temperature patterns and possibly reverse downward trends in yields over the long term as a variety of crops and varieties respond differently to such shocks.

Biodiversity enhances the performance and function of farms because different species or genotypes perform slightly different functions and therefore have different niches (Vandermeer *et al*. 1998). In general there are many more species than there are

Box 2. Temporal and spatial designs of diversified farming systems and their main agroecological effects

Crop Rotations: Temporal diversity in the form of cereal-legume sequences. Nutrients are conserved and provided from one season to the next, and the life cycles of insect pests, diseases, and weeds are interrupted.

Polycultures: Cropping systems in which two or more crop species are planted within certain spatial proximity result in biological complementarities that improve nutrient use efficiency and pest regulation, thus enhancing crop yield stability.

Agroforestry Systems: Trees grown together with annual crops, in addition to modifying the microclimate, maintain and improve soil fertility as some trees contribute to nitrogen fixation and nutrient uptake from deep soil horizons while their litter helps replenish soil nutrients, maintain organic matter, and support complex soil food webs.

Cover Crops and Mulching: The use of pure or mixed stands of grasslegumes, e.g., under fruit trees, can reduce erosion and provide nutrients to the soil and enhance biological control of pests. Flattening cover crop mixtures on the soil surface in conservation farming is a strategy to reduce soil erosion and lower fluctuations in soil moisture and temperature, improve soil quality, and enhance weed suppression, resulting in better crop performance.

Crop-Livestock Mixtures: High biomass output and optimal nutrient recycling can be achieved through crop-animal integration. Animal production that integrates fodder shrubs planted at high densities, intercropped with improved, highly-productive pastures and timber trees all combined in a system that can be directly grazed by livestock, enhances total productivity without need of external inputs.

functions and thus redundancy is built into the agroecosystem. Therefore, biodiversity enhances ecosystem function because those components that appear redundant at one point in time become important when some environmental change occurs. The key here is that when environmental change occurs, the redundancies of the system allow for continued ecosystem functioning and provisioning of ecosystem services. A diversity of species also acts as a buffer against failure due to environmental fluctuations, by enhancing the compensation capacity of the agroecosystem, because if one species fails, others can play their role, thus leading to more predictable aggregate community responses or ecosystem properties (Lin 2011).

Adding Organic Matter To Soils

Many traditional and organic farmers add large quantities of organic materials on a regular basis to their lands via animal manures, composts, tree leaves, cover crops, rotation crops that leave large amounts of residue, etc. as a key strategy used to enhance soil quality. Of utmost importance for resiliency is that soil organic matter (SOM) improves the soil's water retention capacity, enhancing drought tolerance by crops, improves infiltration and diminishes runoff, preventing soil particles from being transported with water under intense rains. SOM also improves surface soil aggregation, holding tightly the soil particles during rain or windstorms. Stable soil aggregates resist movement by wind or water (Magdoff and Weil 2004).

Organically rich soils usually contain symbiotic mycorrhizal fungi, such as arbuscular mycorrhizal (AM) fungi, which form a key component of the microbial populations influencing plant growth and soil productivity. AM fungi are important in sustainable agriculture because they improve plant water relations and thus increase the drought resistance of host plants (Garg and Chandel 2010). The abilities of specific fungus-plant associations to tolerate drought are of great interest in areas affected by water deficits as AM fungi infection has been reported to increase nutrient uptake in water-stressed plants and to enable plants to use water more efficiently and to increase root hydraulic conductivity.

Crop productivity under dry land conditions is largely limited by soil water availability. SOM content (% SOM) is a reliable index of crop productivity in semiarid regions because SOM aids growth of crops by improving the soil's ability to store and transmit air and water, thus enhancing drought resistance. In a study of the semiarid Pampas of Argentina researchers found that wheat yields were related to both soil water retention and total organic carbon (TOC) contents in the top layers (0-20 cm) in years with low moisture availability. Dependence of wheat yields on soil water retention and on TOC contents under water deficit was related to the positive effect of these soil components on plant-available water. Losses of 1 kg SOM ha^{-1} were associated with a decrease in wheat yield of approximately 40 kg/ha. These results demonstrate the importance of using cultural practices that enhance SOM and thus minimize losses of soil organic carbon in semiarid environments (Diaz Zorita *et al.* 1999).

In what is the longest-running, side-by-side comparison of organic and chemical agriculture in the USA, researchers have compared since 1981 the performance of corn and soybean during the transition from chemical to organic agriculture (Rodale Institute 2012). They found that organic corn yields were 31% higher than conventional in years of drought. These drought yields are remarkable when compared to genetically engineered "drought-tolerant" varieties, which saw increases of only 6.7% to 13.3% over conventional (non-drought-resistant) varieties in times of stress (Figure 2).

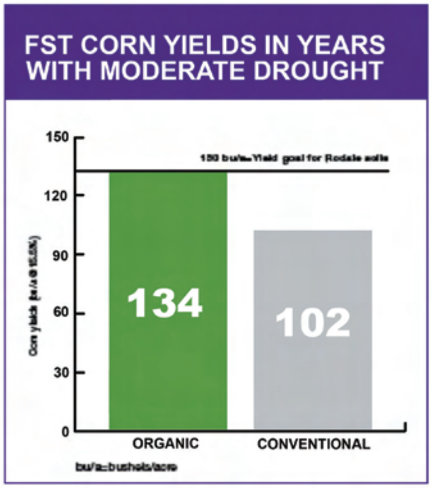


Figure 2. Yields of organic maize are higher than those of conventional maize in years under drought in Pennsylvania, USA, highlighting the role of organic matter in enhancing the soil's water-holding capacity (Reproduced from: Rodale Institute 2012)

Managing Soil Cover

Protecting the soil from erosion and drying up, and improving soil moisture levels and water circulation is also a fundamental strategy to enhance the resiliency of agroecosystems. Cover crops, mulching and green manures offer great agroecological potential as such practices conserve soil, improve the soil ecology, stabilize and enhance crop yield and improve water conservation. Stubble mulching disrupts the soil drying process by protecting the soil surface with residues. Mulching reduces the wind speed by up to 99% and, therefore, losses due to evaporation are significantly reduced. In addition, cover crop and weed residues can improve water penetration and decrease water runoff losses by 2- to 6-fold. The *frijol tapado* or covered bean system is an ancient slash/mulch system common in the hillsides of Central America (Buckles *et al*. 1998). This system of migratory agriculture allows 3-5 months of bean production in one year, taking advantage of the high precipitation and the residual moisture maintained by the slash/mulch after the rains. *Frijol tapado* management consists of first selecting appropriate land and then slashing paths through the vegetation to create access for subsequent planting, broadcasting at high rates (25 to 40 kg of seed ha^{-1}) and slashing of fallow vegetation over the bean seeds. *Frijol tapado* is usually grown on hillsides, preferably facing the morning sun so that leaves and pods of the bean plants dry quickly in the morning (they are susceptible to rot diseases) and the plants receive maximum sunlight, since mornings are often sunny and rain usually falls in the afternoon. Farmers look for land with a cover of tall herbs or low shrubs; there must be enough plant material to provide a mulch which can completely cover the soil. Areas dominated by grasses are avoided since they regrow quickly and compete strongly with the beans. The fields are then left untouched until harvest. Typically, the mulch is not so thick as to result in low bean germination and survival, therefore avoiding low yields, while maintaining soil moisture and protecting the soil against erosion. The absence of burning and cultivation and the presence of thick mulch prevent the germination and growth of weeds. The fallow period reduces the pathogens in the soil, and the mulch protects the bean plants from soil particle splash during rains. The system is adapted to fragile slope ecosystems. The soil is not disturbed by cultivation and the mulch protects it from erosion. Moreover, the natural root system is left intact and the vegetation's fast regrowth further reduces the risk of erosion and restores soil fertility (Buckles *et al*. 1998).

Agroecosystems are more resilient when inserted in a complex landscape matrix featuring genetically heterogeneous and diversified cropping systems managed with organic-matter-rich soils complemented with water conservation and harvesting techniques.

In an effort to emulate and improve the *frijol tapado* system throughout Central America, several non-government organizations have promoted the use of grain legumes as green manure, an inexpensive source of organic fertilizer to build up organic matter (Altieri *et al*. 2011). Hundreds of farmers in the northern coast of Honduras are using velvet bean (*Mucuna pruriens*) with excellent results, including corn yields of about 3,000 kg ha^{-1}, more than double the national average, erosion control, weed suppression and reduced land preparation costs. The velvet beans produce nearly 30 t ha^{-1} of biomass per year, or about 90-100 kgNha^{-1} $year^{-1}$ (Flores 1989). The system diminishes drought stress, because the mulch layer left by *Mucuna* helps conserve water in the soil profile, making nutrients readily available in synchrony with periods of major crop uptake (Bunch 1990).

Taking advantage of well-established farmer-to-farmer networks such as the *campesino a campesino* movement in Nicaragua and elsewhere, the spread of this simple technology has occurred rapidly. In just one year, more than 1,000 peasants recovered degraded land in the Nicaraguan San Juan watershed (Holt-Gimenez 1996). In Cantarranas, Honduras, the massive adoption of velvet bean tripled maize yields to 2,500 kg ha^{-1} while labor requirements for weeding were cut by 75%. In Central America and Mexico, an estimated 200,000 farmers are using some 14 different species of green manure and cover crops (Bunch 1990).

Water Harvesting

In many parts of the world, such as in Sub-Saharan Africa, 40% of the farmland is located in semiarid and dry sub-humid savannahs increasingly subjected to frequent occurrence of water scarcity. However in most years there is more than enough water to potentially produce crops. The problem is that rainfall is concentrated in 2-3 months of the year and/or large volumes of water are lost through surface runoff, soil evaporation and deep percolation. The challenge is how to capture that water, store it in the soil and make it available to crops during times of scarcity. A variety of rainwater harvesting and floodwater harvesting techniques have been recorded in much of the developing world (Reij *et al*. 1996, Barrow 1999).

An old water harvesting system known as *zai* is being revived in Mali and Burkina Faso. The *zai* are pits that farmers dig in often rock-hard barren land, into which water otherwise could not penetrate. The holes are typically between 10-15 cm deep and 20-30 cm in diameter and are filled with organic matter (Zougmore *et al*. 2004). The application of manure in the pits further enhances growing conditions, and simultaneously attracts soil-improving 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 the farmers 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 (Critchley *et al*. 1994).

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. 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 use of *zai* allows farmers to expand their resource base and to increase household security (Reij 1991). 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).

In Niger, traditional planting pits were improved by making them into water-collecting reservoirs, imitating part of a soil improvement technology traditionally used in other parts of the country and in Burkina Faso. From Burkina Faso, it has most recently been reported that villages that adopted land reclamation techniques such as this pitting through crusted soils (filling the pits with manure and water) have seen crop yields rise by 60%, while villages that did not adopt these techniques realized much smaller gains in crop yields (Critchley 1989). In north Nigeria small pits in sandy soil are filled with manure for keeping transplanted tree seedlings wet after the first rains.

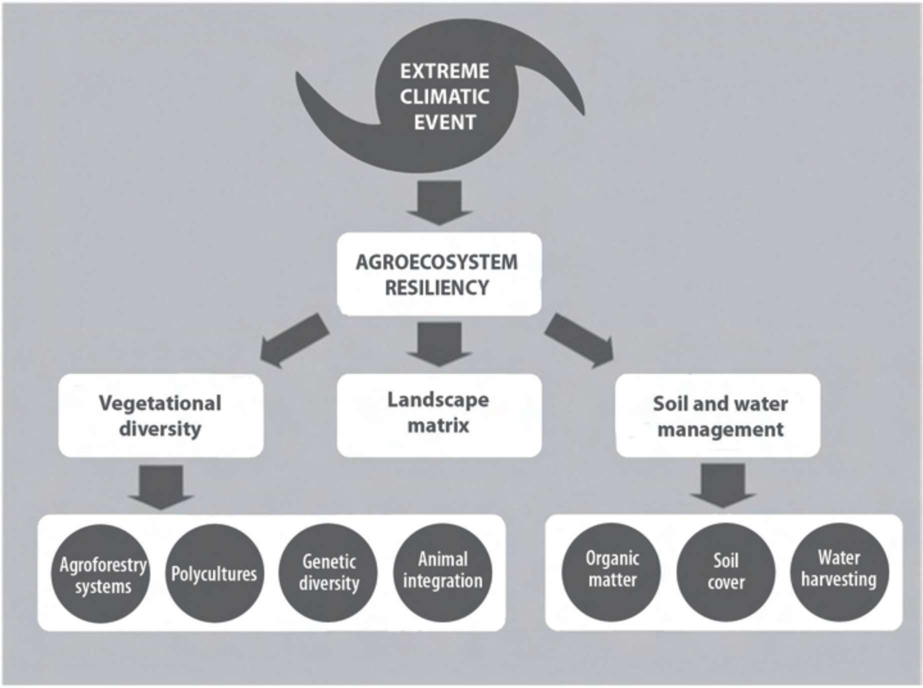


Figure 3. Landscape, farm diversity, soil and water management features that enhance ecological resilience to extreme climatic events

Farmers building infrastructure for water harvesting in La Mixteca Alta in Mexico.

METHODOLOGIES TO ASSESS FARM RESILIENCY

In 2011 a group of Latin American agroecologists associated with REDAGRES: Red Iberoamericana de Agroecología para el Desarrollo de Sistemas Agrícolas Resilientes al Cambio Climático (www.redagres.org) engaged in a two-year survey of small farming systems in selected regions of seven Latin American countries in order to identify systems that have withstood climatic events recently or in the past and understand the agroecological features of such systems that allowed them to resist and/or recover from droughts, storms, floods or hurricanes. The main idea was that identified principles and mechanisms that underlie resiliency would be transmitted to other farmers in the region via field days where farmers can visit the resilient farms and discuss among themselves the features of such farms and how to replicate them in other farms. Cross-visits can also be organized where resilient farmers can visit other communities in other regions and share their experiences, management systems and resiliency strategies.

The group developed a set of simple methodologies with indicators that allow farmers to assess whether their farms can withstand a major climatic event (drought or hurricane) and what to do to enhance the resiliency of their farms. The ultimate goal is to provide information about the main agroecological principles and practices that farming families can use individually or collectively (at the community level) to enhance the adaptability of the farming systems to climate change (Nicholls and Altieri 2013).

Understanding Farmers' Perceptions Of Climate Change

Farmers' ability to perceive climate change is a key precondition for devising strategies to stimulate their choice to adapt and to make the necessary agroecological transition to enhance the resiliency of their farms. This toolkit provides a set of steps that allows users to:

- Assess farmers' perceptions (and their accuracy) of climate trends in the last two decades or so (see Annex 1 which contains a prototype questionnaire), such as changes in temperature and precipitation. For example, a study conducted in the Laikipia District of Kenya found that farmers generally concurred that in the 1960s, 1970s and 1980s when they settled in the study area, rainfall was more regular and predictable in seasons. Rainfall seasons were distinct, but currently, rains have become more unpredictable. In questionnaire interviews, about 88% of the farmers considered the climate at the time of settlement to be ”good” and about 89% of the farmers saw the current climate as “bad”. Farmers constantly stressed declining agricultural production due to unpredictable, sometimes incessant rains on the one hand, as well as low rainfall coupled with high temperatures on the other hand, and the occurence of extreme climatic events including hailstorms, frost and persistent

Table 1. Agroecological practices and their potential to enhance resiliency to climatic stresses through

	Soil organic buildup	Nutrient cycling	> soil cover	Reduce ET	Runoff reduction	> water holding capacity	> infiltration
Diversification							
Mixed or intercropping			✓	✓	✓		
Agroforestry	✓	✓	✓	✓	✓	✓	✓
Intensive silvopastoral system	✓	✓	✓	✓	✓	✓	✓
Crop rotation	✓	✓	✓		✓		✓
Local variety mixtures			✓				
Soil Management							
Cover cropping	✓	✓	✓	✓	✓	✓	✓
Green manures	✓	✓	✓	✓	✓	✓	✓
Mulching							
Compost applications	✓					✓	
Conservation agriculture (organic - no till)			✓	✓	✓		✓
Soil Conservation							
Contour farming					✓		✓
Grass stripings/ living barriers			✓		✓		✓
Terracing					✓		✓
Check dams along gullies					✓		✓

various effects on soil quality and water conservation

Microclimatic amelioration	Reduce soil compactation	Reduce soil erosion	> hydrological regulation	> water use efficiency	> mycorrhizal network
✓	✓	✓		✓	
✓	✓	✓		✓	
✓	✓	✓	✓	✓	✓
	✓	✓		✓	
				✓	
	✓	✓	✓		
	✓	✓		✓	✓
					✓
	✓	✓		✓	
	✓	✓	✓		
		✓	✓		
		✓	✓		
		✓	✓		

Table 2. Farmers' perceptions of climatic variables of Umande and Muhonia sub-locations in Kenya (Reproduced from: Ogalleh *et al.* 2012)

Variable		Umande sub location (% of n)	Muhonia sub location (% of n)	Both sub locations (% of total n)
Current perception of climate	good	7.5	4	5.8
	bad	84.0	95	89.3
	very bad	6.6	0	3.4
	constant	1.9	1	1.5
Perception at settlement time	good	86.8	89	87.9
	bad	11.3	10	10.7
	very bad	0.9	0	0.5
	constant	0.9	1	1.0
Rainfall	increased	3.8	2	2.9
	decreased	92.5	97	94.7
	constant	3.8	1	2.4
Temperature	increased	97.2	95	96.1
	decreased	0.0	3	1.5
	constant	2.8	5	3.9
Wind	increased	95.3	84	89.8
	decreased	2.8	12	7.3
	constant	0.9	4	2.4
	unsure	0.9	0	0.5
Sun's heat	increased	98.1	92	95.1
	decreased	1.9	7	4.4
	constant	0.0	0	0.0
Frequency of droughts	increased	96.2	95	95.6
	decreased	1.9	4	2.9
	constant	1.9	0	1.0
	unsure	0	1	0.5
Frequency of drying rivers	increased	98.1	95	96.6
	decreased	1.9	1	1.5
	constant	0.0	3	1.5
	unsure	0	3	1.5
Incidence of crop diseases	increased	89.6	95	94.3
	decreased	6.6	3.8	10.4
	constant	0.9	0	0.9
	unsure	2.8	0.9	3.8
Incidence of animal disease	increased	54.7	76	65.0
	decreased	20.8	19	19.9
	constant	17.0	4	10.7
	unsure	7.5	1	4.4
Frequency of hunger	increased	97.2	98	97.6
	decreased	1.9	2	1.9
	constant	0.9	0	0.5
Incidence of human disease	increased	75.5	75	75.2
	decreased	10.4	10	10.2
	constant	11.3	4	12.1
	unsure	1.9	2	2.4

droughts (Table 2).

- Understand the factors leading to crop stress. As seen in Figure 4, droughts can result from changes in rainfall patterns (rains ending early or coming late in the growing season) but the growing of monocultures with non-adapted or tolerant varieties and lack of soil organic matter can aggravate crop stress. The situation can become critical if farms have limited access to water resources and their area is subjected to environmental degradation (i.e., soil erosion, deforestation, etc.).

- Assess the coping strategies that farmers use in response to local perception of climate change and variability as well as the effects of such perceived changes. In addition, it is possible to understand what types of remedial or adaptive actions, if any, farmers have undertaken and the effects of such practices in alleviating negative impacts (Table 3). In Kenya most farmers preferred multiple options as coping strategies which were used at the same time. The most widely practiced adaptation on most farms was the diversification of the cropping systems. Farmers in Umande and Muhonia cultivate many crops and varieties simultaneously to reduce the susceptibility of agriculture to micro-climatic events that might result in crop failure. The cultivation of short-cycle and long-cycle crop varieties shows the tendency of farmers to take advantage of the different maturing times of crops to strengthen their resilience to impacts associated with unpredictable rainfall and drier conditions, in order to increase chances of harvesting a crop during the drier and wetter seasons

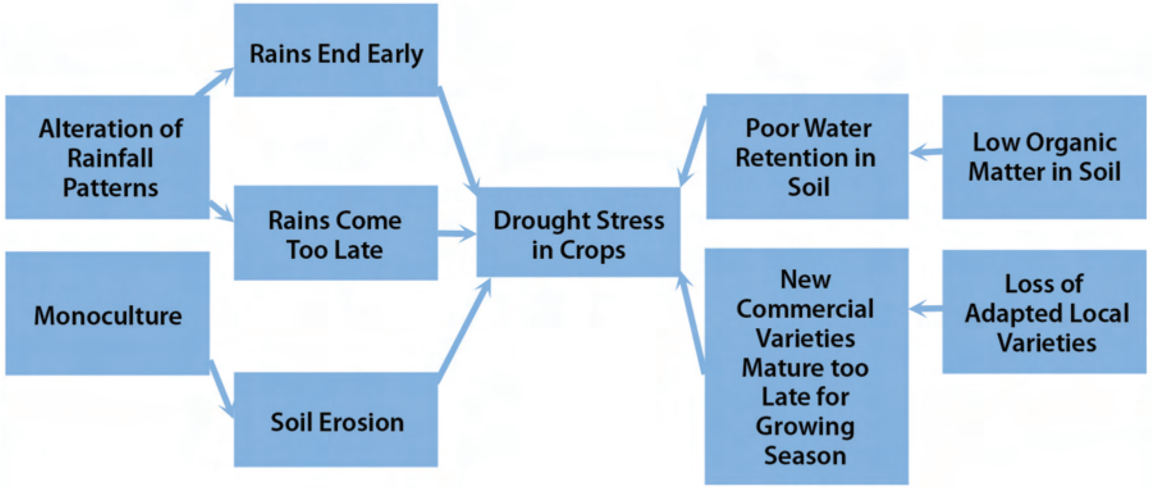


Figure 4. Assessing the root causes of drought stress in crops

Table 3. Coping and adaptation strategies to local perceptions of climate change and variability from Umande and Muhonia sub-locations of Laikipia, Kenya (Reproduced from: Ogalleh *et al.* 2012)

Perception of climate change/variability variable	Perceived effects on humans, livestock, crops	Range of responses Rapid (coping) and longer-term (adaptation)	
		Crops	Livestock
Decreasing Rainfall, unpredictable rainfalls, breaks in rainy seasons early rains late rains	• Humans: hunger, food insecurity, loss of livelihoods • Livestock: Lack of fodder, livestock deaths • crops: loss of crops, loss of seeds	Use early maturing crop varieties e.g. 511, 513; DHO4, DHO2) use late maturing crop varieties such as 614, 628, 611 early planting late planting planting whenever a spell of rains is determined) continuous planting rain harvesting into manually dug water pans irrigation from water pans seed preservation using local innovative techniques e.g. wood ash and use of expired batteries making shallow basins around every crop	crop residues used as livestock feeds grass growing for sale during droughts livestock watering from water pans
Increasing frosts	• Humans: frostbites • crops: frostbites	Planting *Ricinus communi* around the farm/plot Planting frost resistant crops e.g. 614	
Increase incidence of crop pests, diseases, animal pests and diseases	• Humans: sickness • Livestock: poor livestock health, low production, death of livestock • crops: poor yields, loss of crops	Seek agricultural extension services, use local knowledge such as wood ash to destroy pests	Seek veterinary services, use of local knowledge to treat diseases (hot rod to burn swollen lymph nodes)

Table 3. *Cont.*

Perception of climate change/variability variable	Perceived effects on humans, livestock, crops	Range of responses Rapid (coping) and longer-term (adaptation)	
		Crops	**Livestock**
Increasing temperatures	• Humans: hunger, food insecurity, loss of livelihoods • Livestock: drying of pasture and grass leads to lack of fodder, death of livestock • crops: loss of crops, loss of seeds	Mulching to reduce loss of water from soils Irrigation from water pans	Shifting from crop production to livestock keeping
Increasing wind	• crops: falling of cultivated crops	Intercropping maize, beans, potatoes; growing castor oil plant (*Ricinus communis*) (locally referred to as *mbariki*) around the farm/plot	
Increasing frequency of droughts	• Humans: hunger, food insecurity, loss of livelihoods • Livestock: Lack of fodder, death of livestock • crops: loss of crops, loss of seeds	Use early maturing crop varieties e.g. 511, 513 DHO4, DHO2) use late maturing crop varieties such as 614, 628, 611 use of certified seeds conservation agriculture planting in shallow trenches mulching relocating to river banks to access river water for irrigation cultivation of commercial horticultural crops (tomatoes, peas, cabbages)	Migrating with livestock to forests Sale of livestock Buy feed for livestock

(Ogalleh *et al.* 2012).

- Evaluate the level of farmers' knowledge of appropriate adaptation measures to confront climatic variability as well as the accessibility, feasibility and adoptability of such measures. One village, for example, might focus on assessing the potential of various innovations to deal with water shortages by using simple ranking methods to evaluate the impacts of each innovation on productivity, stability, equity and sustainability at the community level (Table 4). The + sign indicates a positive impact of the innovation and the value of 1 signifies that the innovation is feasible, is of low cost and will bring rapid benefit. Roof catchment and shallow wells seem appropriate innovations which make possible the creation of food and market gardens, but this will require particular attention to ensuring enough water during the dry season. The plan then should outline specific interventions for deciding where to place the garden and the wells (or other water source), determining the size of the gardens

Table 4. Mbusyani options assessment chart ranking best water management practices to overcome dry periods (Chambers 1983)

Best bet or innovation	productivity	Stability	Sustain-ability	Equita-bility	Time to benefit	Cost	Technical & social feasibility	Priority
Boreholes	?	0	-	0	3	3	3	6
Roof catchment	+	+	++	+	1	1	2	3
Natural springs	+	+	+	++	1	2	2	
Rehabilitate dams	++	+	++	++	1	2	2	
Shallow wells	+	+	++	0	2	1	2	
New surface dams	++	+	++	++	1	2	2	

Key

-	Negative impact
0	No impact
+	Positive impact
?	Unknown
++	Very positive impact

	Time	Cost	Feasibility
3	Long	High	Low
2	Medium	Medium	Medium
1	Short	Low	High

based on the water harvested and what crops would be grown, giving preference to varieties that do not demand too much water.

- Discover barriers to adaptation cited by farmers and ways to overcome them.

A Diagnosis Of The Vulnerability Of Farms To Extreme Climatic Events

When trying to arrive at a set of farmer-friendly indicators that allows a diagnosis of the vulnerability of a group of farms to a strong storm, hurricane or drought in a specific region, it is useful to derive the indicators from farmers answering the following question: *If a hurricane or drought were to strike your farm, would the farm resist? Yes or no and why?* This would immediately prompt farmers to talk about the unique features of their farms and management practices (crop diversity, soil conservation practices, root depth, drainage, etc.) as well as their surrounding landscape (slope and exposure, proximity of forests, windbreaks, etc.) that they believe help their farms resist (or not) the climatic event.

The methodology consists in the observation of several features of the farm and its surrounding landscape matrix. These features are, according to farmers' perceptions and knowledge (and also the scientific literature), the most relevant to consider when evaluating the level of damage that a farm would exhibit after an event such as a strong rain storm or prolonged drought. As an example, Box 3 provides the indicators to be observed to assess whether a cacao agroforestry system would resist the

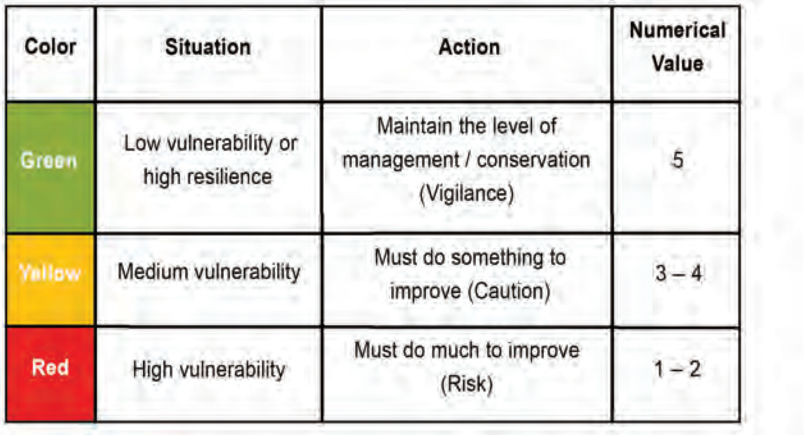
Complex cacao-based agroforests in Costa Rica could better resist the impacts of strong storms.

impact of a hurricane in Central America. The same methodology can be used to assess the susceptibility of farms to a drought using indicators listed in Box 4.

Rural producers in the Sahel deal with unpredictable weather conditions all the time. Many households depend on many strategies to deal with such unpredictability:

- Spreading risk by distributing livestock among different herders.
- Keeping a variety of breeds and species of livestock adapted differentially to stress.
- Spreading risk by having multiple fields in different areas with various soil types.
- Using early-maturing plant varieties and selecting for drought-tolerant genetic diversity.

The Central American team used a *"semaforo"* (traffic lights) system as a method that allows farmers to rank each indicator as red (high risk-values 1-2 on a scale of 1-5), yellow (medium risk-values 3-4) or green (little or no risk, value of 5). The colors prompt farmers to think about what it means when a set of indicators exhibit the color red or yellow and the consequences of a farm indicator remaining in yellow or red, and therefore start thinking about



Color	Situation	Action	Numerical Value
🟩 Green	Low vulnerability or high resilience	Maintain the level of management / conservation (Vigilance)	5
🟨 Yellow	Medium vulnerability	Must do something to improve (Caution)	3 – 4
🟥 Red	High vulnerability	Must do much to improve (Risk)	1 – 2

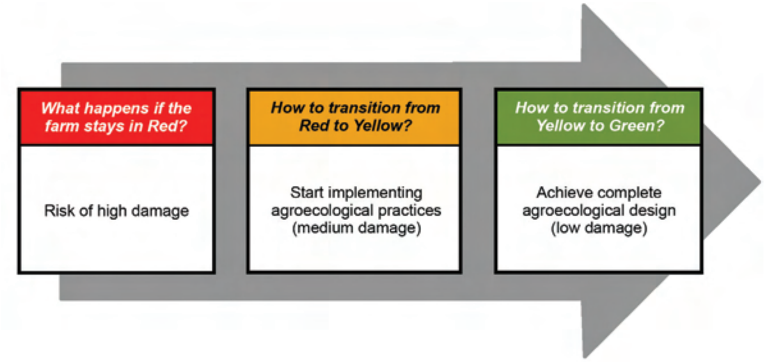


Figure 5. A *semaforo* (traffic light) system assigning colors to the degree of vulnerability and resilience of a particular farm and the actions to take in order to transition the system to a higher resilience state

Box 3. Farm and landscape features to be observed to assess the readiness of agroforestry systems to resist the impact of a hurricane

Landscape level

Landscape diversity: This refers to the mix of mosaics of natural areas and production systems in the surveyed region, including forest patches, hedgerows, cropping systems and their slope and exposure, water courses, etc. The higher the landscape diversity, the lower are the chances that a disaster will cause damage, as surrounding forests can protect against winds and regulate local water cycles, and when crops are grown at various altitudes, slopes and exposures damage levels can be reduced.
Slope: The steeper the slope, the higher the expected damage by rains if no conservation practices are in place.
Exposure of the hillside: Crops grown on hillsides directly exposed to dominant and strong winds will suffer more damage and are potentially subjected to mudslides.
Proximity to forests or protective hills: Farms adjacent to forests or hills that intercept dominant winds and rains are generally less exposed to the effects of hurricanes.
Windbreaks and/or hedgerows: Depending on the vegetational structure (species composition, density and stratification), location, etc., these structures can intercept dominant winds and exert a protective role.
Proximity to rivers: Farms located in lower zones close to rivers can suffer flooding when excess rain occurs.

Farm level

Plant diversity: The higher the plant diversity and complexity (vertical stratification) of the farm, the more resistant the agroforestry system will be to impacts of hurricanes.
Root depth: Trees with deep roots tend to hold the soil and are more resistant to being uprooted by strong winds.
DAP (diameter at chest level): The higher the DAP value and the more vigorous the tree, the lower the possibility of branches breaking and the tree falling.
Soil structure: Soils with good aggregation exhibit high infiltration rates, thus avoiding saturation and runoff.
Soil cover: Soils with a thick mulch or a living cover crop exhibit lower erosion rates.
Soil conservation practices: Practices such as mulching, living or dead barriers, terraces and contour planting protect soils from the erosive effect of runoff.
Drainage: The presence of infiltration trenches, drainage canals and other works are key to deviating excess water and diminishing water velocity and landslides.
Food self-sufficiency (% of family food produced in the farm): The higher the degree of self-sufficiency of a family, the less the family will depend on external supplies of food which may be interrupted by heavy storms or hurricanes.
Level of farmer knowledge and skills on adaptive practices: Farms managed by farmers with higher skills and knowledge about adaptive practices will better resist hurricanes and will recover their productive capacity faster after the event.

Box 4. Farm and landscape features to be observed to assess the susceptibility of a farming system to droughts

Landscape level

Landscape diversity: Farms surrounded by forests, windbreaks and other types of natural vegetation suffer less drought as this vegetation protects against dessicating winds and tends to regulate local water cycles.

Exposure of the hillside: Crops grown on hillsides directly exposed to dominant and strong winds will suffer more evapotranspiration and desiccating effects of winds.

Proximity to water sources: Farms located near water sources (rivers, creeks, ponds, etc.) can extract water for irrigation in times of need.

Farm level

Crop diversity: Crops grown in agroforestry systems suffer less evapotranspiration losses and thus can better endure drought periods. Intercropping buffers losses due to drought as one crop species may be susceptible while others are tolerant.

Crop varieties: Local or native (landrace) varieties are usually more tolerant to low water regimes than improved and/or commercial varieties.

Soil cover: Soils covered with thick mulch suffer less evaporation losses.

Organic matter: Additions of organic matter in the form of compost, manure and plant debris increase soil water retention capacity. Organically rich soils also have more microbial diversity (such as mycorrizhae) which can enhance water use efficiency of crops.

Conservation of seeds: Farmers that conserve a rich diversity of crop varieties with differing degrees of adaptation to drought can better withstand the effects of lack of water.

Food self-sufficiency (% of family food produced in the farm): The higher the degree of self-sufficiency of a family, the less the family will depend on external sources of food which may become scarce or expensive in times of drought.

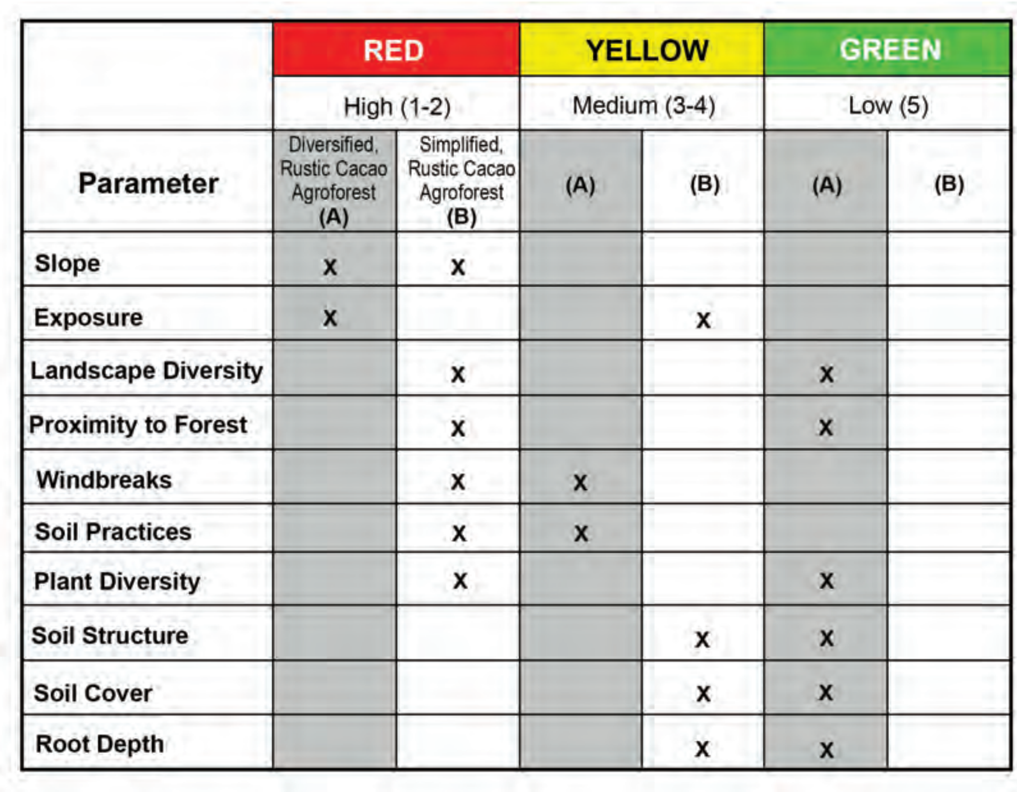
Level of farmer knowledge and skills on adaptive practices: Farms managed by farmers with higher skills and knowledge about adaptive practices, including tolerant crops and varieties, will better resist droughts and will recover their productive capacity faster after the event.

what to do to transition the system towards a state of higher resilience, towards green (Figure 5).

Table 5 shows the results of a group's comparative evaluation of two cacao farms (a simplified cacao agroforest associated with banana compared with a multistrata diversified cacao agroforest). As observed, indicators in the diversified farm exhibited more yellow and green scores (only two red scores) than the simplified system which exhibited six red scores. When the color scores are converted to numbers and displayed in an amoeba-type diagram, it is clear that the diversified cacao system exhibits more optimal values, reflecting a higher level of resilience than the simplified cacao system (Figure 6). Obviously the simplified cacao system requires agroecological interventions to enhance the values of the red and yellow indicators, transitioning them towards green.

According to farmers' observations, the most vulnerable points of the simplified cacao system were linked to: steep slope, low plant stratification and crop diversity, lack of soil conservation practices and absence of hedgerows and/or windbreaks.

Table 5. Indices of vulnerability as perceived by farmers in two cacao agroforestry systems in Talamancan, Costa Rica



	RED		YELLOW		GREEN	
	High (1-2)		Medium (3-4)		Low (5)	
Parameter	Diversified, Rustic Cacao Agroforest (A)	Simplified, Rustic Cacao Agroforest (B)	(A)	(B)	(A)	(B)
Slope	x	x				
Exposure	x			x		
Landscape Diversity		x			x	
Proximity to Forest		x			x	
Windbreaks		x	x			
Soil Practices		x	x			
Plant Diversity		x			x	
Soil Structure				x	x	
Soil Cover				x	x	
Root Depth				x	x	

The indicators that exhibited yellow and red colors included: landscape diversity, slope exposure, soil cover, tree root depth, proximity to protecting forests and farmers' knowledge about adaptive practices. Therefore the group recommended the following practices to enhance the resistance of the simplified cacao farms to possible hurricanes:

- Increase the diversity of shade trees and the number of tree strata
- Improve soil cover with litter or cover crops
- Enhance addition of organic matter to improve soil structure and infiltration
- Implement soil conservation practices such as living or dead barriers following the contour
- Establish living fences or windbreaks with multiple use trees and shrubs to protect against dominant winds

After the diagnosis is conducted, farmers can implement the recommended practices, and later observe the performance of their agroforestry systems after a climatic event. Farmers can conduct a number of observations and simple measurements after a storm event and thus assess the level of damage:

- Superficial soil depth: the loss of 1 cm of superficial soil is equivalent to approximately 50-100 t/ha/year.
- Mudslides: number per area (per 100 m^2 or hectare) and severity (% farm surface affected).
- Number of gullies (number per area, and % of farm area with gullies, severity in m^3/ha).
- Signs of erosion: gullies, emergence of roots or stones, etc.
- Number and % of damaged or fallen trees.
- Loss of flowers, fruits, branches, % yield loss, etc.
- Net economic loss.

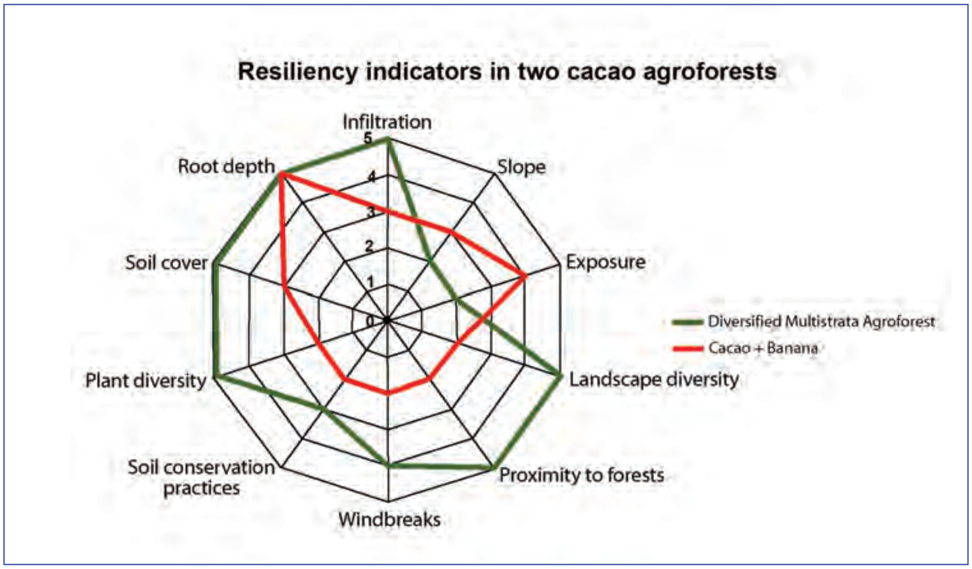


Figure 6. An amoeba exhibiting resiliency indicator values in two agroforestry systems (diversified vs simplified agroforest) in Costa Rica

- Number of trees not affected, or % trees that recover and rate of recovery.

It is also instructive for farmers in a region to gather and share observations and analyze as a group the performance of the various systems. In the case of Central America, after conducting the field assessments, farmers shared observed information leading to the following reflections:

- Agroforestry systems (AFS) in slopes are more susceptible than AFS located in valleys.
- Younger AFS are more vulnerable.
- Cacao grown in monoculture or with one stratum of a single tree species suffers more damage than more complex cacao AFS.
- In AFS the highest tree strataum suffers more damage from strong winds, while lower strata are more protected and suffer less damage.
- Often winds force leaf fall from higher trees, allowing penetration of sunlight to the lower strata, thus stimulating compensatory regrowth.
- AFS with high levels of soil litter and/or cover suffer less erosion and conserve more soil moisture.
- Certain shade tree species (citrus, avocado, mango) are more tolerant to drought periods than other species.

Using the conceptual resiliency framework described on page 2 of this booklet, the REDAGRES teams engaged in agroecological research in selected farming systems in each country, and developed a methodology to understand the agroecological features of the farming systems and the social strategies used by farmers that allowed them to resist and/or recover from droughts, storms, floods or hurricanes (Nicholls and Altieri 2013). To illustrate the application of the methodology, data is presented from two case studies conducted in: (a) Carmen del Viboral, Antioquia, Colombia, and (b) Mixteca Alta, Oaxaca, Mexico.

Carmen del Viboral

In this study a team composed of researchers and local farmers jointly developed a set of indicators to estimate vulnerability and capacity of response on six farms exhibiting similar slope and exposure conditions (three agroecological farms and three farms managed conventionally).

The team developed indicators to estimate vulnerability (slope, landscape diversity, soil's susceptibility to erosion) and capacity of response (soil conservation practices, water management practices, crop diversity levels, food self-sufficiency, etc.). By actually giving values (from 1-5; values close to 1 or 2 express a higher level of vulnerability) to these indicators, it was possible to compare the farms in an amoeba diagram (Figure 7). Clearly the agroecological farms (green) were less vulnerable than the conventional ones (red). The team also applied 13 indicators to assess the capacity of response exhibited by the farmers, and clearly again the agroecological farms (green) exhibited higher response capacity than the conventional ones (red) (Figure 8).

Using the averages of the vulnerability and capacity-of-response indicators and converting them to percentages and giving a value to the threat (as % yield loss or % damage), the values are plotted in a risk triangle. This allows visualization of a farm's position in a risk gradient in order to determine which are the farms that are at high risk (high vulnerability, low capacity

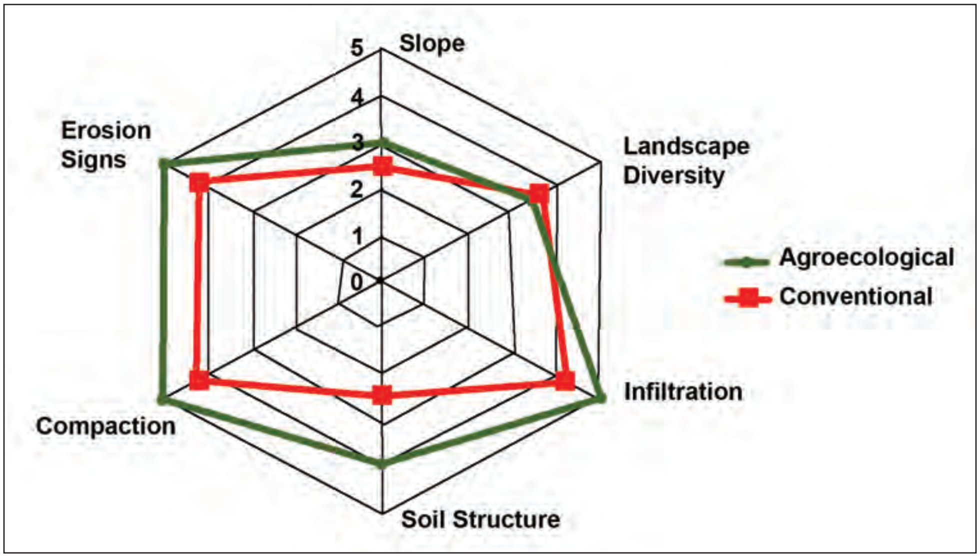


Figure 7. An amoeba showing the values of vulnerability indicators as measured in conventional (red) vs agroecological (green) farms in Antioquia, Colombia. Values close to 1 or 2 express a higher level of vulnerability.

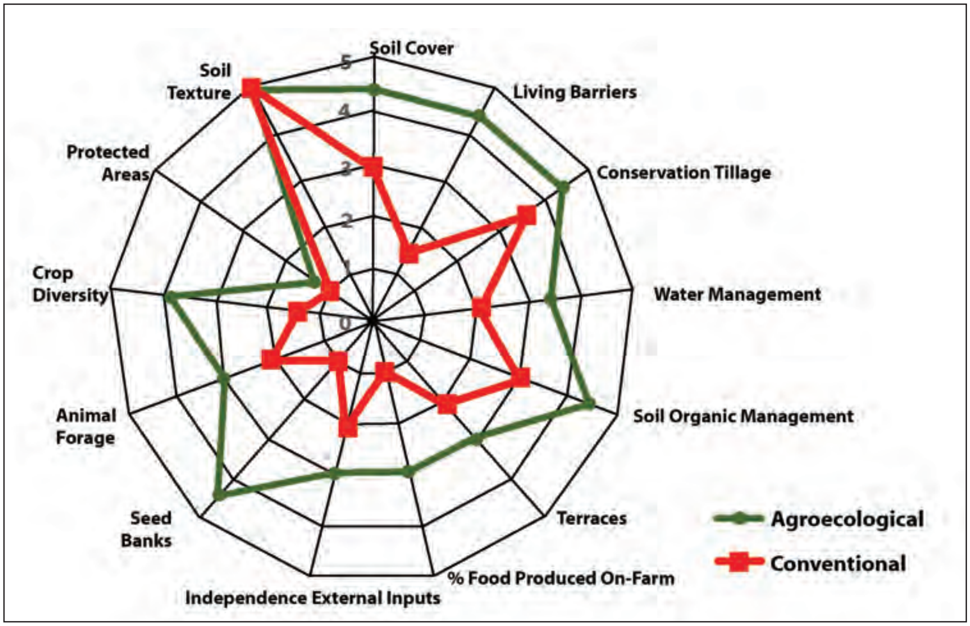


Figure 8. An amoeba depicting values of indicators of response capacity of farmers managing conventional (red) vs agroecological (green) farms in Antioquia, Colombia. Values of 4 or higher denote a greater capacity of response by farmers and therir farming systems.

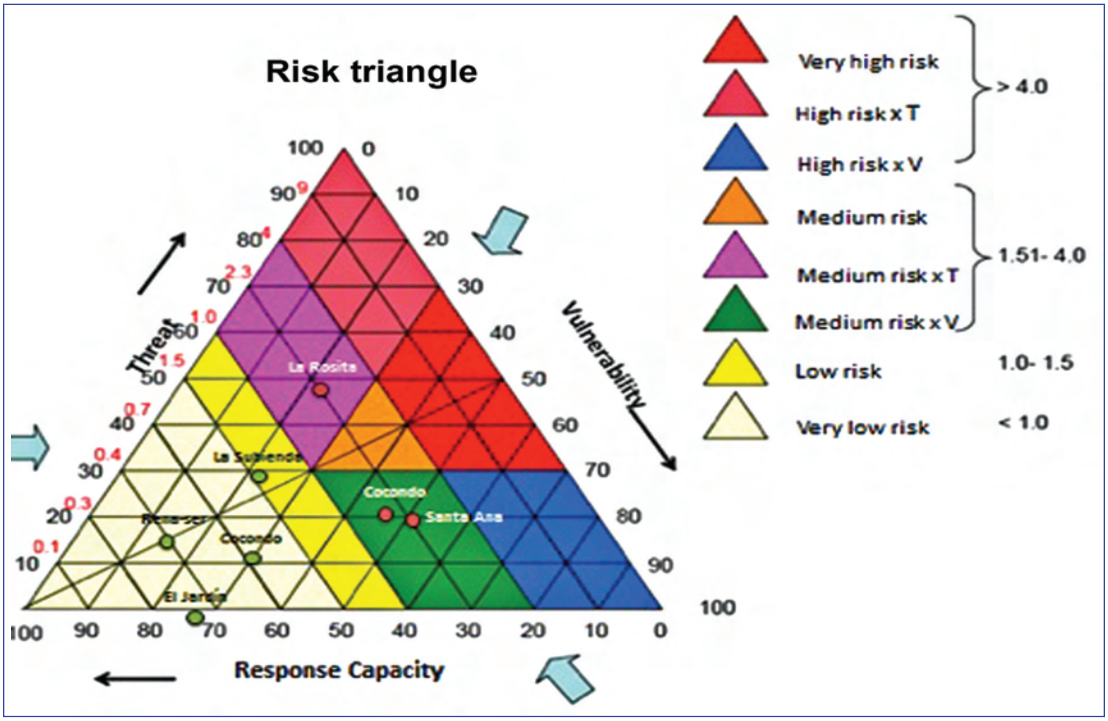


Figure 9. A risk triangle showing the location of agroecological (green dots) and conventional (orange dots) farms in Antioquia along a gradient of vulnerability and response capacity indicator values. Farms in the bottom left of the triangle exhibit the highest resiliency (Henao, unpublished data).

of response and high losses) and at low risk (low vulnerability, high capacity of response and low losses). In the Carmen del Viboral case study it was clear that the agroecological farms (green dots in Figure 9) exhibited low vulnerability due to their high response capacity relative to the conventional farms (orange dots in Figure 9), which exhibited higher vulnerability and a lower response capacity.

Mixteca Alta

This study conducted in Oaxaca, Mexico describes how small farmers adapted to and prepared for past climate challenges, and also depicts what they are doing in the present to deal with recent increases in temperature and rainfall intensity, and later rainfall onset (Rogé *et al.* 2014). Farmers identified 14 indicators to evaluate the adaptive capacity of four agroecosystems located in Zaragoza and El Rosario communities using the form described in Table 6. Researchers pooled the agroecosystem evaluations within each community by assigning numerical scores of 0 for marginal (marked with sad faces), 1 for acceptable (neutral faces), and 2 for optimal (happy faces). Farmers analyzed the outcomes by drawing bar plots of the pooled scores for their community. The farmers were prompted to analyze the

Table 6. Description of landscape, farmer management and soil quality indicators in La Mixteca Alta (Rogé *et al.* 2014). Farmers rank each indicator as marginal (marked with a sad face), acceptable (with a neutral face) or optimal (with a happy face). The challenge is how to obtain more happy faces (i.e., the optimal condition) in the landscape, farmer management and soil quality categories.

Team:
Community:
Production system:

Category	Indicator	Marginal	Acceptable	Optimal
Landscape	– Territorial composition			
	– Windbreaks			
	– Field location			
	– Soil conservation			
Farmer management	– Crop rotation			
	– Crop varieties			
	– Polyculture			
	– Soil amendments			
	– Soil cultivation			
Soil quality	– Spontaneous plants			
	– Soil productivity			
	– Soil organic matter			
	– Soil depth			
	– Soil texture			

results of their evaluations as a group by answering the following questions:

- How to obtain more happy faces (i.e., the optimal condition) in the landscape, farmer management and soil quality categories?
- How to maintain the happy faces (i.e., optimal condition) that you already have in the landscape, farmer management and soil quality categories?

At the landscape level, farmers observed that vegetated borders and perennial vegetation with multiple uses mitigated exposure to extreme climatic events. Similarly, in a nearby area farmers recognized that heterogeneous and forested landscapes protected fields, bringing rain, retaining groundwater, accumulating soil organic matter, and controlling insect pests. In another community participants described how contour ditches capture soil and water, and a slight slope to the contour ditches avoids flooding and breaching during heavy rainfall events.

Indicators of farmer management at the field level included the importance of crop genetic and species diversity for stabilizing overall yields given the variation in crop performance from year to year. The indicator of "soil amendments" was derived from farmer testimonies that synthetic fertilizer only improved crop yields with favorable rainfall; in drought years, synthetic fertilizer was ineffective and "even burned crops". Some participants recommended substituting synthetic fertilizers with

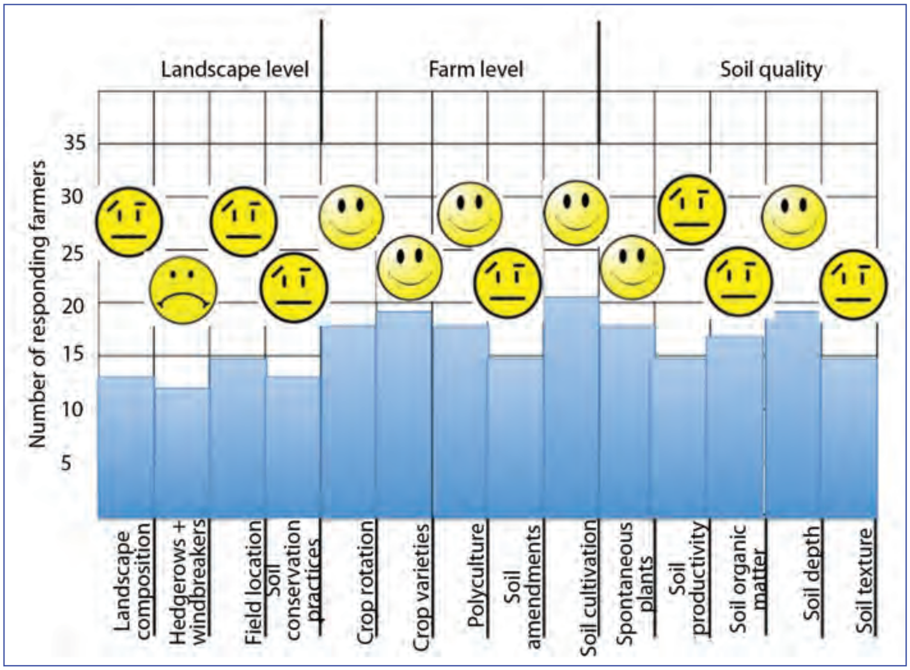


Figure 10. Mosaic plot of evaluations of four agroecosystems using 14 indicators that were conducted by farmers in each of the communities of La Mixteca Alta. The y-axis represents the number of farmers' rankings for the agroecosystems in their community along an ordinal scale of marginal, acceptable and optimal (depicted by the different faces above the bars). The 14 indicators are grouped into those operating at the landscape level, those directly influenced by farmers' management and those describing soil quality (Rogé *et al.* 2014).

various locally derived soil amendments, including animal manures, worm castings, forest humus, and human urine.

Soil quality was also described by farmers as affecting the impact of climatic variability on agroecosystems. The three communities associated soil moisture retention with soil texture and depth. Generally, clayey soils were described as the most productive in drought years, but also difficult to cultivate in wet years. In contrast, farmers described sandy soils as the easiest to cultivate in wet years but also the least productive. Farmers considered deep soils, measured by how far the Egyptian plow entered the soil, to be the most productive soils in both wet and dry years.

The application of indicators led to assessments which showed that farmers consider their field-level management to be largely appropriate (Figure 10). Soil quality received a close to equally divided ranking between optimal and the combined rankings of acceptable and marginal. In contrast, landscape indicators received higher numbers of acceptable and marginal rankings compared to optimal rankings. Soil quality indicators had mixed rankings, while landscape-level indicators were in greatest need of improvement.

The lowest and highest scored indicators served as points of departure for discussing how farmers could sustain the optimal conditions of their agroecosystems while improving the marginal ones. Farmers' analysis of their evaluations identified multiple local strategies to better prepare for climatic variability (Table 7). Strategies recommended by farmers for improving their agroecosystems given climatic variability involved establishing perennial vegetation and adopting more soil conservation strategies along field margins (e.g., agroforestry, terraces, contour ditches and stone borders). In response to low scores for landscape indicators, Zaragoza farmers proposed planting fruit trees and acacia at the edges of fields to diversify the production of food, forage and fodder, as well as to stabilize soils. Some farmers recommended making better use of stone borders (*camellones*) for stabilizing soils, given local soil conditions.

Table 7. Strategies proposed by farmers for dealing with climatic variability after applying indicators in La Mixteca Alta (Rogé *et al.* 2014)

Category	Strategies for moving towards optimal
Landscape	– Education of community members – Plant trees for fruit, fodder, etc.; protect them from animals with fences – Improve livestock management – Construct contour ditches – Maintain windbreaks
Farmer management	– Apply animal manures and composts – Relax weeding – Cultivate soil with the oxen – Respect the seasons – Harvest water
Soil quality	– Plant fruit trees and acacia – Sow green manures – Apply animal manures and composts – Avoid synthetic fertilizers

References

Altieri MA, Funes-Monzote FR, Petersen P (2011) Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty. *Agron. Sustain. Dev.* doi: 10.1007/s13593-011-0065-6.

Altieri MA, Nicholls CI (2004) *Biodiversity and pest management in agroecosystems.* Second edition, Haworth Press, New York.

Altieri MA, Nicholls CI (2013) The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change* doi: 10.1007/s10584-013-0909-y.

Altieri MA, Nicholls CI, Henao A, Lana MA (2015) Agroecology and the design of climate change resilient farming systems. *Agronomy for Sustainable Development* doi: 10.1007/s13593-015-0285-2.

Barrow CJ (1999) *Alternative irrigation: the promise of runoff agriculture.* Earthscan Publications, Ltd., London.

Bianchi FJJ, Booij CJ, Tscharntke T (2006) Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. *Proceedings of the Royal Society B: Biological Sciences* 273:1715-1727; doi: 10.1098/rspb.2006.3530.

Buckles D, Triomphe B, Sain G (1998) *Cover crops in hillside agriculture: farmer innovation with Mucuna.* International Development Research Center, Ottawa.

Bunch R (1990) Low-input soil restoration in Honduras: the Cantarranas farmer-to-farmer extension project. Sustainable Agriculture Gatekeeper Series SA23, IIED, London.

Cabell JF, Oelofse M (2012) An indicator framework for assessing agroecosystem resilience. *Ecology and Society* 17(1):18.

Chambers R (1983) *Rural Development: Putting the Last First.* Longman, Harlow, UK.

Critchley WRS (1989) Building on a tradition of rainwater harvesting. *Appropriate Technology* 16(2):10-12.

Critchley WRS, Reij C, Willcocks TJ (1994) Indigenous soil and water conservation: a review of the state of knowledge and prospects for building on traditions. *Land Degradation and Rehabilitation* 5:293-314.

Diaz-Zorita M, Buschiazzo DE, Peineman N (1999) Soil Organic Matter and Wheat Productivity in the Semiarid Argentine Pampas. *Agronomy Journal* 91:276-279.

Flores M (1989) Velvetbeans: an alternative to improve small farmers' agriculture. *ILEIA Newsletter* 5:8-9.

Folke C (2006) Resilience: the emergence of a perspective for social ecological systems analyses. *Global Environmental Change* 16:253-267.

Garg N, Chandel S (2010) Arbuscular mycorrhizal networks: process and functions. *Agronomy for Sustainable Development* 30:581-599.

Harvey CA, Chacón M, Donatti CI, Garen E, Hannah L, Andrade A, Bede L, Brown D, Calle A, Chará J, Clement C, Gray E, Hoang MH, Minang P, Rodríguez AM, Seeberg-Elverfeldt C, Semroc B, Shames S, Smukler S, Somarriba E, Torquebiau E, van Etten J, Wollenberg E (2014) Climate-Smart Landscapes: Opportunities and Challenges for Integrating Adaptation and Mitigation in Tropical Agriculture. *Conservation Letters* 7:77-90; doi: 10.1111/conl.12066.

Holt-Gimenez E (1996) The campesino a campesino movement: farmer-led, sustainable agriculture in Central America and Mexico. Food First Development Report No. 10, Institute of Food and Development Policy, Oakland.

Lin B (2011) Resilience in agriculture through crop diversification: adaptive management for environmental change. *BioScience* 61:183-193.

Lin BB (2007) Agroforestry management as adaptive strategy against potential microclimate extremes in coffee agriculture. *Agricultural and Forest Meteorology* 144:85-94.

Loreau M *et al*. (2001) Biodiversity and ecosystem functioning: Current knowledge and future challenges. *Science* 294:804-808.

Magdoff F, Weil R (2004) Soil organic matter management strategies. In: Magdoff F, Weil R (eds) *Soil Organic Matter in Sustainable Agriculture.* CRC Press, Boca Raton, pp 44-65.

Murgueitio E, Calle Z, Uribea F, Calle A, Solorio B (2011) Native trees and shrubs for the productive rehabilitation of tropical cattle ranching lands. *For Ecol Manage* 261:1654-1663.

Natarajan M, Willey RW (1986) The effects of water stress on yield advantages of intercropping systems. *Field Crops Research* 13:117-131.

Nicholls CI, Altieri MA (2013) *Agroecologia y cambio climatico: metodologias para evaluar la resiliencia socio-ecologica en comunidades rurales.* Red IberoAmericana de Agroecologia para el desarrollo de sistemas agricolas resilientes al cambio climatico (REDAGRES). Gama Grafica, Lima.

Ogalleh SA, Vogl CR, Eitzinger J, Hauser M (2012) Local Perceptions and Responses to Climate Change and Variability: The Case of Laikipia District, Kenya. *Sustainability* 4(12): 3302-3325; doi: 10.3390/su4123302.

Reij C (1991) Indigenous Soil and Water Conservation in Africa. IIED Gatekeeper Series No. 27, London.

Reij C, Scoones I, Toulmin C (1996) *Sustaining the soil: indigenous soil and water conservation in Africa.* Earthscan, London.

Rodale Institute (2012) *The farming systems trial: celebrating 30 years.* Rodale Press, Pennsylvania.

Rogé P, Friedman AR, Astier M, Altieri MA (2014) Farmer strategies for dealing with climatic variability: a case study from the Mixteca Alta Region of Oaxaca, Mexico. *Agroecology and Sustainable Food Systems* doi: 10.1080/21683565.2014.900842.

Scherr SJ, McNeely JA (2008) Biodiversity conservation and agricultural sustainability: towards a new paradigm of "ecoagriculture" landscapes. *Philosophical Transactions of the Royal Society B: Biological Sciences* 363:477-494; doi:10.1098/rstb.2007.2165.

Swiderska K *et al.* (2011) The role of traditional knowledge and crop varieties in adaptation to climate change and food security in SW China, Bolivian Andes and coastal Kenya. IIED, London.

Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I, Thies C (2005) Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. *Ecology Letters* 8:857-874.

Vandermeer J (1989) *The Ecology of Intercropping.* Cambridge University Press, Cambridge.

Vandermeer J, van Noordwijk M, Anderson J, Ong C, Perfecto I (1998) Global change and multi-species agroecosystems: concepts and issues. *Agriculture, Ecosystems and Environment* 67:1-22.

Webber LM, Ison RL (1995) Participatory Rural Appraisal Design: Conceptual and process issues. *Agricultural Systems* 47:107-131.

Zougmoré R, Mando A, Stroosnijder L (2004) Effect of soil and water conservation and nutrient management on the soil-plant water balance in semi-arid Burkina Faso. *Agricultural Water Management* 65:102-120.

Annex 1. Questions to assess farmers' perceptions of climate change

Farmer's name:
Region:
Municipality:

Name of the farm:
Farm size:

1. Changes

Has climate changed in your region?
Yes No

If yes, how does this change manifest itself?
More rain
More temperature
Frosts
Floods
More winds
Less rain
Less temperature
Droughts
Mudslides

Why do you think climate change happens?

2. Perceived Effects

Effects related to insect pests
Increase which?
Decrease which?
New pest which?

Effects related to diseases
Increase which?
Decrease which?
New disease which?

Effects related to the soil
Erosion
Compaction
Less fertility
Mudslides
Floods
Others, which?

Which are the main crops you grow?

Which crops and varieties were more affected?

How has production changed?

Increased

Dropped

Quality Improved? Worsen?

Which systems were less affected?

Monocultures

Mixed crops

Agroforestry systems

Other

Which varieties were most affected?

Comercial/improved

Local/native

3. Practices

Which practices have you implemented to lower impacts of climate change in your farm?

Soil management

Describe the practice(s)

Pest and disease management

Describe the practice(s)

Water management

Describe the practice(s)

Enhancement of plant diversity in the farm

Describe how

Improvement of the landscape matrix surrounding your farm

Describe how

Do you think these practices helped?

Yes A lot Average Just a little

No

Which one?

Which problems have you experienced to implement these adaptation practices?

4. Institutions

Have you received support from any institution?

Yes Which?

No

Have they provided technical advice?

Yes Which?

No

Was this recommendation useful?

Yes Why?

No

Have they offered you credit or help facilitating adoption of adaptative practices?

Yes

No

What kind of support do you require from such institutions?

Do you belong to an organization or group?

Yes Which?

No

Does this organization work on initiatives related to climate change?

Yes No Which?

Are there community networks in your village?

Yes Which?

No

What type of activities do these networks undertake in case of disasters?

Does your community have seed banks or granaries?

The capacity of farms to adapt to and recover from extreme events such as hurricanes and severe drought has assumed urgent importance in an era of climate change. This booklet serves as a methodological toolkit aimed at aiding farmers and technicians to build farming systems that are more resilient to climate variability. It identifies the agroecological principles and practices which enhance resiliency, underlining the need, among others, for crop and genetic diversity at the farm and landscape levels. On this basis, the authors go on to suggest indicators to evaluate the level of vulnerability of farms and, accordingly, enable farmers to improve their response capacity in the face of growing climatic unpredictability.

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