Sustainable Development Department

BUILDING RESILIENCE FOR AN UNPREDICTABLE FUTURE:

HOW ORGANIC AGRICULTURE CAN HELP

FARMERS ADAPT TO CLIMATE CHANGE

by

Sarah Borron

Food and Agriculture Organization of the United Nations

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SCOPE OF THIS PAPER

In the face of global climate change, farmers must adapt their practices to deal with changing temperatures and more frequent extreme weather events. These adaptations must first and foremost build resilience within the agroecosystem, increasing its ability to continue functioning when faced with unexpected events. Climate change adaptation as a topic broadly encompasses many fields and areas where response will increasingly be needed. This paper focuses on climate change adaptation for farmers, especially those in Least Developed Countries (LDCs). These farmers are among the most vulnerable to climate change because they rely heavily on agriculture as their primary sector and need affordable solutions, based on their own resources and skills, to prevent excessive losses.

This paper has chosen to explore the potential of Organic Agriculture (OA) in adaptation efforts because ecological approaches to food production offer farmers in LDCs affordable, accessible opportunities to strengthen their farms' resilience. While certified organic farmers are relatively uncommon in developing countries, though their numbers are increasing, millions of farmers in LDCs base their farming practices on ecological principles acquired through millennia of experimentation and adaptation to local conditions. OA relies as much as possible ecological processes and on a farm's own resources, which reduces monetary costs to farmers and reduces the non-renewable resources used in farming. It is therefore assumed that OA offers adaptation options that allow farmers to use on-farm resources to build resilience, rather than rely on expensive external inputs. Many indigenous farming practices are already based on ecology, and combining the best of traditional knowledge with support from ecological science offers farmers in developing countries an opportunity for success.

This paper examines the role of organic farming techniques in increasing resilience in the following areas: (i) soil and water; (ii) biodiversity and landscapes; and (iii) community knowledge systems. Soil, water and biodiversity provide the basis for a farm's success, and enhancing landscape management builds upon healthy natural resources to create sustainable systems. Communities develop in-depth knowledge, adaptive techniques, and even specific crop and livestock varieties for their local ecosystems; ways to preserve and share this knowledge are as important as the farming practices themselves. Each section describes how OA practices can be used to strengthen land, water, biodiversity and community systems, in anticipation of change that may be expected from uncertain climatic conditions.

Not every organic farmer uses every technique discussed, and not every technique is appropriate to OA only. What is unique to OA is its systemic approach throughout the food production chain. This paper presents under each section the basic organic principles and requirements and examines the best organic practices relevant to LDC farmers. This paper does not focus on farmers using organic monocultures for commodity production, but rather on small-scale farmers using diversified OA techniques primarily for subsistence, with some market involvement. More reductionist versions of OA may focus more on input substitution than relying on ecological processes for farming needs, which reduces resilience. Specialization also increases the risk involved in farming. Furthermore, this paper examines adaptation potentials, thus limiting considerations on mitigation to a summary in the Introduction. Assessing the impact of climate change on agricultural resources is outside the scope of this paper.

INTRODUCTION

Impact of climate change on developing country farmers

Climate change holds the potential to radically alter agroecosystems in the coming decades, and devastating crop failures are already evident in several countries of the world. Global warming will not only increase global mean temperatures, but will also increase the frequency of extreme weather events and the variability of weather in general (Tompkins and Adger, 2004). We may expect changes in land vegetation, ocean circulation, sea surface temperature and global atmosphere composition, which will in turn impact rainfall patterns (Salinger, et al., 2005).

These changes will bring new challenges to farmers. The Intergovernmental Panel on Climate Change (IPCC) expects that world production of food should remain steady through the next century with less certainty beyond that point (Burton and Lim, 2005). Other sources are more cautious, warning that climate change may depress yields in already food-insecure areas or that previous changes in global climate have had negative impacts on production as a whole (Fuhrer, 2003; Tompkins and Adger, 2004). Even if overall production remains high, certain regions will experience devastating declines. Temperature increases in the tropics, for instance, may render many current crops unfit for the area (Burton and Lim, 2005).

Farmers in LDCs face stark challenges. Nearly 60% of the population of LDCs are farmers, who contribute over 30% of the Gross Domestic Product of these nations (Kandlikar and Risbey, 2000). Individual farmers in developing countries often rely on their production not only for income but as a main source of food. In a world in which millions of people already go hungry, such losses are a matter of grave concern. Every effort must be made to prevent these losses, rather than focus on ways to cope after disaster has occurred. Many agricultural systems provide necessary environmental services that are also vulnerable to the effects of global climate change.

Climate change is likely to disproportionately affect farmers in LDCs. Much research has indicated that marginalized communities suffer the most from altered environmental conditions (Tompkins and Adger, 2004). Poverty already exists in fragile arid and mountainous regions that may respond more quickly to climate change (Altieri and Nicholls, 2006). The IPCC names rainfall variability and related disasters as “the single most determining factor endangering agricultural production in developing countries” (Stigter, et al., 2005). Perhaps the most certain feature of global climate change is its unpredictability, as it is unknown which regions will face longer dry spells and which will face heavier monsoons, which regions will face stronger cyclones and which regions may be spared.

Need for adaptation

Farmers in developing countries need tools to help them adapt to these new conditions. Adaptation in agriculture is certainly not new. Changing weather has always concerned farmers, and they have developed ways to respond. The phenomenon of global climate change makes the ability to adapt even more important, as adaptation will need to occur at a much faster pace. IPCC (2001) defines adaptation to climate change specifically as “adjustment in natural or human systems in response to actual or expected climatic *stimuli* or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation."

As so many of the changes cannot be foretold specifically, farmers must be able to increase their farms' resilience to change. Resilience has been described as a system's ability to maintain normal functions in the face of unexpected conditions. Applied to agriculture, the concept also includes the farm's dependence on its own resources instead of external inputs and the farmer's ability to experiment with different practices and learn what works best (Milestead and Darnhofer, 2003; Wall and Smith, 2005). As farmers observe conditions and develop responses to current challenges, they hone skills necessary to adapt to climate change as well (Tompkins and Adger, 2004). Communities as a whole increase their resilience when they develop information and support networks to handle new challenges (Tompkins and Adger, 2004).

Farmers in developed countries may include in their response to climate change increased inputs such as synthetic fertilizers and pesticides and capital investments in irrigation and greenhouses to help their crops survive. Farmers in developing countries--and small holders in general--have a much smaller set of options and must rely to the greatest extent possible on resources available on their farms and within their communities. OA, with the due knowledge of ecological processes, offers farmers in LDCs many affordable, accessible opportunities to strengthen their farms' resilience.

What is organic agriculture?

Organic agriculture (OA) provides a broad set of practices that increase resilience in farms. OA is based on a rigorous standard requiring no synthetic inputs, instead using practices modelled on ecological processes to increase soil fertility and ward off pests. The Codex Alimentarius Commission (2001) defines OA thus:

> "Organic agriculture is a holistic production management system which promotes and enhances agroecosystems health including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, cultural, biological, and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system"

This definition serves as the baseline for OA around the world. Countries develop their own standards from those set out by the Codex Alimentarius Commission. Although OA adheres to certifiable standards, farmers can do much more to base their practices in ecology than standards require. The principles of OA concern the way people interact with living landscapes, relate to one another and shape the legacy of future generations. The International Federation of Organic Farming Movements (IFOAM) describes four principles of organic farming, upon which its standards are based. Each of the principles contributes to the long-term health of the farm, the surrounding environment, and the farming participants, which in turn builds resilience for the long-term success of the farm. The principles are the following:

- "Health: OA should sustain and enhance the health of soil, plant, animal, human, and planet as one and indivisible.
- Ecology: OA should be based on living ecological systems and cycles, work with them, emulate them, and help sustain them.

- ♦ Fairness: OA should build on relationships that ensure fairness with regard to the common environment and life opportunities.
- ♦ Care: OA should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment" (IFOAM, 2006).

Although OA is not designed with climate change adaptation as a primary goal, OA's systemic, ecological approach inherently includes positive side effects, including reduced greenhouse gas emissions and strengthened adaptation strategies, especially for small holders who stand to suffer the most from climate change.

Organic agriculture's potential to mitigate climate change

OA has a role to play in climate change adaptation and mitigation, including avoided damage, and many farming practices contribute to both processes. As this paper focuses on adaptation issues, this section summarizes briefly OA contribution to mitigation measures.

Agriculture is a major contributor to climate change globally, chiefly in terms of methane and nitrous oxide emissions from livestock production and soils. Since the 1990s, agriculture has been responsible for 15% of total greenhouse gas emissions worldwide, accounting for one-quarter of carbon dioxide emissions, two-thirds of methane emissions and nearly all nitrous oxide emissions (Kotschi and Muller-Samann, 2004). Should direct and indirect sources of carbon emissions be considered, such as processing and transportation of foods, it might well be that our food system releases more greenhouse gases into the atmosphere than cars do!

Agriculture also has the potential to avoid climate change through emission reductions and mitigate climate change through carbon sequestration. While individual practices could be implemented on almost any farm, OA is unique in creating a whole system of agriculture based on ecological principles from production to consumption by privileging closed energy and nutrient cycles at the farm and by promoting short supply chains.

While agriculture's mitigating potential is not nearly enough to prevent climate change from happening, its potential to reduce climate change is quite significant, particularly in concert with reforms of industries aiming at reducing energy use and promoting renewable energy sources. OA is often ignored in discussions of climate change mitigation, but is worth considering, especially if the processes described below are scaled up through conversion of larger agricultural areas and more research. In France, for instance, it has been estimated that a national conversion to OA could possibly decrease greenhouse gas emissions by 10% including: carbon sequestration (-4% from increasing carbon in soils of 7-10 million tonnes per year); nitrous oxide (-3% from organic soil management); methane (-1% from enhanced manure management); carbon dioxide (-2% from no use of chemical fertilizers and decreased transport and greenhouse cultivations) (Claude Aubert, *personal communication*).

Carbon sequestration:

- ♦ Organic soil management focuses on increasing soil organic matter, which increases carbon sequestered in the soil. Several studies have shown that feeding soils annually with organic matter in excess of the mineralized quantity is the only way to increase soil organic carbon. Organic practices that do so include addition of manure and plant residue to the fields, mixed cropping, green manuring, legume based crop rotations, agroforestry and minimum tillage. An eighteen year study comparing fields fertilized organically versus fertilized with mineral fertilizers found that the organic fields sequester three to eight more tons of carbon per hectare (Kotschi and Muller-Samann, 2004).

- ♦ OA conversion in orchards often entails changes from annual cropping or bare soils on the orchard floor to more permanent plant cover that sequester more carbon.
- ♦ Agroforestry, often used in tropical organic systems, sequesters significant amounts of carbon in the trees. Depending on the region of the world and the harvesting rate, agroforestry systems can sequester between 9 and 63 tons of carbon per hectare (Kotschi and Muller-Samann, 2004).

Carbon dioxide emissions:

- ♦ OA encourages minimal clearing and burning of vegetation and developing more permanent cropping systems that return biomass to the soil.
- ♦ OA does not use energy-intensive synthetic fertilizers and pesticides, thus avoiding the fossil fuels used to make these products and to transport them to the farm. Studies from different countries have found 30-70% less energy consumption per unit of land for organic systems compared to similar conventional systems (Kotschi and Muller-Samann, 2004).
- ♦ In organic livestock production, animal feed tends to be produced on the farm, saving fossil fuel use for shipping feed. IFOAM standards require that at least 50% of feed be produced on the farm or on organic farms within the region.
- ♦ In general, OA privileges local produce, minimally packaged and processed commodities and short supply chains, thus contributing to reduced energy consumption.

Nitrous oxide emissions:

- ♦ Nitrous oxide emissions occur from all uses of fertilizer. Total nitrogen concentration in the application and the plants' capacity to absorb it determine the amount of emissions. OA is less likely to over-apply nitrogen due to its use of less concentrated forms of fertilizer. The distribution of organic fertilizer throughout the year as well as the nature of the soil and its humidity have a role to play in the degree of nitrous oxide emissions. Still, the fact that nitrous oxide emissions are proportional to nitrogen inputs results in decreased emissions in organic systems as compared to conventional ones.
- ♦ Improved ruminant diets reduce nitrous oxide emissions. In one study, diets with lower protein and higher fibre contents result in reducing emissions by 10-15% (Kotschi and Muller-Samann, 2004). There may be trade-offs, though, between the production of nitrous oxide with respect to the meat and milk productivity of the animals.
- ♦ Livestock concentrations are kept low, so the manure produced is not too much to be applied to the land.

Methane emissions:

- ♦ Not all organic practices reduce methane emissions. Specifically, increased biological activity in the soil can increase methane emissions, actually putting OA at a disadvantage in this regard, especially in humid soils. Furthermore, organic ruminants may produce more methane due to extensive pastures. This is partially compensated for by the fact that organic milking cows live longer, thus producing less methane in their life span. (Methane is mostly produced during the first two, unproductive years of the animal's life.)
- ♦ Compost, which is recommended in OA, emits less methane than manure application because it ferments aerobically rather than anaerobically.
- ♦ Improved ruminant diets can substantially reduce methane emitted in the animals' flatulence, due to bacterial fermentation of feed in the animal's main stomach. A study in Germany found a 42% reduction in methane emissions from cows by including sunflower seeds in their diets (Kotschi and Muller-Samann, 2004). In New Zealand, cows fed with

forage legumes containing condensed tannins were identified as having lowered methane emissions (New Scientist, 2006). Research is continuing on the way ruminants metabolise their food, towards the goal of reducing methane emissions.

- More research must be done to reduce methane emissions from rice paddies in organic systems, but there are several possible means to do so.

ORGANIC AGRICULTURE AND CLIMATE CHANGE ADAPTATION

This chapter describes how OA can contribute to climate change adaptation. Each section has a box describing the organic standards related to the topic. Although there is great convergence between the Codex Alimentarius Commission and IFOAM standards, the latter International Basic Standards are used because these are revised by the organic farming community every three years and are thus more up-to-date. These standards represent a baseline from which farmers can build their own systems, often going much farther towards ecological principles.

Soil and water resources: the basis of production

Without healthy soils and sufficient water, no agriculture is possible. Changes in temperature, precipitation and other atmospheric conditions due to global warming will directly change soils. While specific impacts are incredibly difficult to predict for individual areas, expected extreme weather events will almost certainly damage soils and accelerate erosion (Rounsevell, et al., 1999). Higher temperatures may increase frequency of droughts and reduce areas under permafrost (Rounsevell, et al., 1999). Extremes in rainfall may leave soils too wet or dry for tillage at crucial periods. Efficient irrigation systems will become a necessary component of farms in water-stressed regions.

Organic standards for soil and water resources

Principles:

- Organic farming methods conserve and grow soil, maintain water quality and use water efficiently and responsibly.
- Soil and soil management is the foundation of organic production. Organic growing systems are soil based care for the soil and surrounding ecosystems and provide support for a diversity of species, while encouraging nutrient cycling and mitigating soil and nutrient losses.
- Organic farming returns microbial plant or animal material to the soil to increase or at least maintain its fertility and biological activity.
- Organic livestock husbandry is based on the harmonious relationship between land, plants and livestock, respect for the physiological and behavioural needs of livestock and the feeding of good-quality organically grown feedstuffs.

Requirements:

- There must be minimum crop rotations and minimum vegetation cover in perennial systems.
- Nutrients and organic matter removed from the soil from harvesting should be returned.
- Livestock should not be over-grazed, nor are landless systems permitted.
- Burning vegetation must be kept to a minimum.
- Farmers must not deplete or overuse water resources and must seek to preserve water quality. Water recycling must be used when possible.
- Farmers must prevent or take steps to remedy soil and water salinization.

Soil management in organic systems

There are many opportunities to improve the quality of agricultural soils, leading to higher productivity and better responses to extreme conditions. Conventional agriculture relies on external inputs, namely chemical fertilizers, for soil fertility. OA relies on management of natural cycles to add crucial nutrients, increase soil organic matter and protect the soil from erosion. As crops deplete nutrients, the addition of nutrients restores fertility for future crops. Soil organic matter determines much about the soil's quality as it "is an important substrate of cationic exchange, is the warehouse of most of the nitrogen, phosphorus, and sulphur potentially available to plants, is the main energy source for microorganisms and is a key determinant of soil structure" (Ewel, 1986). Soil organic matter also helps soils retain moisture (Altieri and Nicholls, 2006). Rain and wind both erode soils, costing the farmer loss of fertility and contaminating local waterways. OA practices ultimately increase long-term soil productivity, lending greater stability to the system (Thrupp, 2000).

Good soil fertility and tilth form the basis of sound organic management, and farmers practice a variety of techniques to ensure soil quality. OA farmers develop complex crop rotations. These rotations incorporate crops with different nutrient needs, allowing maximum use of soil nutrients. Rotations additionally break weed and insect pest life cycles, reducing the interventions necessary for pest management. Rotations typically include a fallow period in which the soil rests; plant residues from what grows on the field during that time are tilled back into the soil to add nutrients and soil organic matter. Farmers may specifically sow a leguminous cover crop during the fallow period, or incorporate a legume at some point in the rotation, which produces nitrogen to be used by later crops (Fragstien, 1996). Fields may be used alternately for crops and for livestock pasture; livestock consume weeds and naturally fertilize the soil with their waste. Materials that might otherwise be viewed as waste are crucial for nutrient management in organic systems. Once returned to the soil, crop residues and animal waste add nitrogen and soil organic matter. Waste materials can also be composted. Plant residues are often added to livestock waste and allowed to mature into manure, which better balances the nutrient composition before being returned to the fields (Piorr, 1996).

While the above-described practices add fertility to the soil, another set of practices prevents loss of soil through erosion. Cover crops help hold the soil in place during fallow periods. Permanent vegetation, such as trees and hedge-rows, on the borders of fields protects fields from strong winds and storms. Such vegetation also provides benefits for biodiversity, as will be discussed in the next section. Shelterbelts in Africa have also been used to reclaim desertified areas by blocking hot winds and retaining moisture, and traditional seed holes called "zai" are used in the Sahel to restore arid and crusted areas of fields (Stigter, et al., 2005).

OA has been criticised for its use of tillage in weed management, which can contribute to soil erosion on organic farms. However, most organic farmers use the minimum tillage necessary for their farming system.

Maintaining soil quality and preventing erosion leads to healthier crops which are better able to survive. Plants that are not already stressed by lack of water or nutrients can withstand extreme events more effectively.

Water management in organic systems

By increasing soil organic matter, soil management techniques become water management techniques as well. A study comparing fields managed under conventional and organic systems found that the organically-managed farmers fared significantly better during drought. Researchers speculated that organically managed soils had better water holding capacity due to increased soil organic matter. Interestingly, the same fields fared better during extreme rainfall, absorbing more water and experiencing less runoff and erosion (Lotter, et al., 2003). Water absorption is necessary for groundwater recharge, an environmental service that protects the whole ecosystem. Another study of Central American smallholder farms after Hurricane Mitch found that those who used sustainable soil management practices, including intercropping, composting, and terracing, recovered much more quickly from the devastation (Tengo and Belfrage, 2004). Both of these studies indicate that organic management can help protecting soil and water during extreme weather.

In the face of climate change, farmers may need to take extra steps to ensure water availability. Various techniques for water harvesting, infiltration pits to collect water, and the cultivation of drought-tolerant crops have all been used in Zimbabwe as a means to improve access to water (Salinger, et al., 2005). Permaculture, the design of holistic, edible landscapes adapted to the local area, is also common in many places (ATTRA, 2006). Mulching helps retain soil moisture and ultimately adds organic matter back to the soil (Tengo and Belfrage, 2004). Ultimately, irrigation may be necessary to adapt to reduced rain in certain areas. OA practices form the basis for protecting as much available moisture as possible in the face of challenges in finding sufficient quality and quantity of water for irrigation (Rousenvell, et al., 1999).

Biodiversity and landscapes: security in redundant systems

As temperatures increase and weather patterns shift, ecosystems will change drastically. As the climate changes, habitats will become less suitable for some species and more suitable for others. These changes will happen across biological kingdoms and likely encourage migration of species to more suitable locations for their survival. In some cases, habitats will become like other known habitats, but others may be completely new. In agriculture, these changes may mean certain crops can no longer be grown where they currently are while others will be more appropriate. Weeds, fungal diseases, beneficial and pest insects all may change range, creating new situations for farmers to address.

Organic standards for biodiversity and landscapes

Principles:

- ♦ Organic farming benefits the quality of ecosystems. Agroecosystem management should maintain, improve, and close ecological cycles. It should also facilitate biodiversity and protect and conserve the landscape.
- ♦ Species and varieties cultivated in organic agriculture systems are selected for adaptability to the local soil and climatic conditions and tolerance to pests and diseases. All seeds and plant material are certified organic.
- ♦ Organic farming systems apply biological and cultural means to prevent unacceptable losses from pests, diseases and weeds. They use crops and varieties that are well-adapted to the environment and a balanced fertility program to maintain fertile soils with high biological activity, locally adapted rotations, companion planting, green manures, and other recognized organic practices as described in these standards.

Requirements:

- ♦ Farmers must take measures to improve the landscape and biodiversity.
- ♦ Farmers must not clear primary ecosystems.
- ♦ Farmers may not use genetically modified organisms.
- ♦ Wild harvest products must be harvested at a sustainable rate from a defined area where prohibited substances are not applied. Such harvest should not endanger the existence of any species.
- ♦ Farmers should maintain a significant portion of their farms to facilitate biodiversity and nature conservation. A farm should place appropriate areas under its management in wildlife refuge habitat. These include:
    - o extensive grassland such as moorlands, reed land or dry land;
    - o in general all areas which are not under rotation and are not heavily manured: extensive pastures, meadows, extensive grassland, extensive orchards, hedges, hedgerows, edges between agriculture and forest land, groups of trees and/or bushes, and forest and woodland;
    - o ecologically rich fallow land or arable land;
    - o ecologically diversified field margins;
    - o waterways, pools, springs, ditches, floodplains, wetlands, swamps and other water rich areas which are not used for intensive agriculture or aquaculture production;
    - o areas with ruderal flora (i.e., plants growing in marginal areas of the farm);
    - o wildlife corridors that provide linkages and connectivity to native habitat

Requirements specifically aimed at protecting biodiversity are often general but IFOAM goes about as far as any standard by requiring even in the *aquatic* context that "Production should maintain the aquatic environment and surrounding aquatic and terrestrial ecosystem, by using a combination of production practices that…provides for biodiversity through polyculture and maintenance of riparian buffers with adequate plant cover" (9.2, Aquatic Ecosystems).

(IFOAM, 2006)

Agrobiodiversity: mimicking Nature to increase resilience

In order to determine how an agroecosystem will respond to changes, one must ask to what extent the agroecosystem mimics Nature. Fields of genetically-identical crops facing a previously unknown pest may suffer great losses; history has recorded such devastations as the Irish potato famine and Southern corn blight in the U.S., both caused in part by the genetic uniformity of the crops (Stuthman, 2002). Biologically diverse systems are much more complex and rely on many relationships within the system. As climate change occurs, the ecosystem on a diversified organic farm is more likely to go through natural stages of succession, adapting in ways that prevent whole agroecosystem collapse.

Conversion of land to agricultural use has modified habitats for species around the world, and increasing population pressures cause agriculture to compete with wilderness as a land-use in many ecologically sensitive regions. Simplifying farms by growing monocultures and removing vegetation in the margins further reduces biodiversity in and around farms. Such practices not only cause environmental damage but create agroecosystems that will be less resilient to climate change. Organic farms, on the other hand, are designed with biodiversity in mind, as diverse ecosystems provide a number of important services on the farm (Scialabba and Williamson, 2004; Altieri and Nicholls, 2006). It is important to note that these services are developed on the farm and rely on farmers' knowledge, not external inputs, making such approaches particularly valuable in developing countries (Pimbert, 1999). Agricultural biodiversity includes not only the genetic resources of crops and livestock, but the diversity of species that support production and those in the wider environment as well, such as soil micro-organisms, pollinators and pest predators. When farmers design practices to enhance biodiversity not just on the farm but in the surrounding ecosystems, it can strengthen both the farm and the environment. For example, a wild area can provide predator habitat that reduces pests.

Organic practices that enhance biodiversity

OA utilizes various combinations of plant and animal species in time and space. Some organic systems are more diverse than others. Crop rotations (i.e. diversity in time) are a requirement of organic standards. Polycultures (i.e. diversity in space, specifically within the fields themselves) are not required on organic farms, but certainly fall within organic standards and are quite common on farms in developing nations, especially in tropical climates. Polyculture on small-scale farms and home gardens is widespread throughout Central America, Southeast Asia, and sub-Saharan Africa (Scialabba and Hattam, 2003). Tropical agriculture in particular includes complex agroforest polycultures with multiple year rotations and long fallow periods (Altieri and Nicholls, 2006; Ewell, 1986). Organic shade-grown coffee is an example of an effective means of using OA for agroforestry (Thrupp, 2000).

Organic standards also require farmers to use organic seeds and encourage genetic diversity in both crops and livestock. Organic farmers, particularly those in developing countries who cannot afford to buy their own seed, rely on saving their seeds year after year. Farmers select seeds from successful plants and in so doing develop local landraces, defined as "geographically or ecologically distinctive populations which are conspicuously diverse in their genetic composition" (Thrupp, 2000). The combination of these efforts increases farms' resemblance to natural ecosystems, thereby enhancing resilience.

Crop rotations are the most basic and common form of diversity on organic farm. As discussed above, organic farmers rotate crops and livestock from one part of the farm to another rather than grow the same product over and over in the same space. This practice provides multiple benefits for soil quality, as we have seen, and also helps to break pest and disease life cycles and maximizes efficient use of soil nutrients and water (Ewel, 1986). Some farmers also use multiple sowing dates, thereby lessening the chance that the whole crop will be at a critical stage during an extreme weather event (Tengo and Belfrage, 2004).

Livestock can play an important role in nutrient cycling. In Peru, cattle graze on crop residue, meanwhile fertilizing the land with their waste, as part of a long rotation that includes quinoa, maize, alfalfa, potatoes, peas, wheat, and other crops (Scialabba et al., 2002). Most crop rotations include a fallow period in which a piece of land is allowed to rest. In the humid tropics, such fallow periods are particularly important as they break pest life cycles that winter would disrupt in temperate regions. Tropical agroforestry includes rotations that may last several years. Fallow periods are often longer in these systems, allowing succession to occur as in a natural forest and contributing vital nutrients to soils often subject to leaching (Ewel, 1986). Practices that increase soil health and reduce pests make crops healthier and thus more able to withstand changes in climate.

Diversity in space involves polyculture or intercropping. Simply put, these practices involve growing more than one crop in the same field. Such fields may involve alternating rows of two or more crops, or a crop grown underneath trees. Polycultures may also be so complex as to be indistinguishable from the natural landscape to the untrained eye. Polycultures reduce risk, for if one crop fails, there are still several others which may succeed. In the case of an extreme weather event, some crops may be more able to survive than others, and different crops may respond better to drought versus a storm, for instance, and vice versa, helping to manage variable conditions. Interestingly, well-chosen polycultures tend to increase productivity. Not every crop has the same nutrient and moisture needs at the same time, so the plants use resources more efficiently than if only one crop is planted in the same area. Thus, the total productivity of all the crops grown in one area is often higher than if only one crop had been planted (Scialabba and Hattam, 2003; Altieri and Nicholls, 2006).

A diverse landscape offers many more opportunities to manage pests. Polycultures can distract pests, as the field does not offer the feast that a monoculture does, and organic farmers often place certain plants around the borders of fields that repel pests (Ewel, 1986). Pesticides used in conventional agriculture often cause collateral damage (i.e. beneficial insects) which can then not be relied upon to enhance the agroecosystem. Organic farmers, on the other hand, design their plantings to attract pollinators and pest predators. Farmers may include plants that are not useful as edible crops simply because of their important role in pest management. These plantings combined with natural vegetation on the edges of fields and woodlots create a habitat that can support beneficial species and the wildlife of the area in general (Tengo and Belfrage, 2004). Because of the system's diversity, polycultures are less vulnerable to new pests or to the loss of a beneficial insect, as is likely to happen as habitats shift under the influence of climate change. Overall, diversity in the agroecosystem supports diversity in the surrounding environment, which increases the larger ecosystem's ability to cope with climate change as well (Thrupp, 2000). Given the importance of environmental services off the farm, practices that encourage resilience in the whole landscape are important indeed.

Not only are whole agroecosystems diverse, but the very crops and livestock grown represent many generations' worth of selecting seeds and breeding livestock that survive well in a given area. Thus, farmers have developed unique landraces specifically adapted to survive under local conditions. The diversity of local landraces is much higher than modern cultivars. Such diversity and adaptation certainly increase resilience on the farm. While modern varieties engineered for one or maximum two desirable genetic traits may offer the opportunity of high yields with heavy use of external inputs, such varieties are more vulnerable to changing conditions. Local landraces, on the other hand, tend to offer the stability of more consistent yields even in bad years (Stigter, et al., 2005). The following examples (Scialabba, et al., 2002) illustrate how farmers have revitalized the use of landraces to increase resilience:

- A group of Indonesian farmers, known collectively as "Pusspaindo" became frustrated by the environmental and health effects of conventional rice farming and have returned to using their own varieties under organic management. The farmers have found this change to be easier and more economical, as well as offering a wider array of tastes in rice. .
- Peruvian farmers are growing genetically diverse cotton varieties that naturally produce a range of colours. The genetic diversity helps improve their farming operation, and the environmentally-friendly production methods appeal to consumers, helping ensure a market.
- South African farmers, faced with an outbreak of Newcastle disease in their chickens, found that their original breeds were more disease-resistant and also foraged a wider variety of food and survived better under extreme conditions.

Seed banks around the world collect varieties of seeds for the use of future generations. OA agriculture helps preserve not only the seeds, but the practices that required to grow them (Thrupp, 2000). As climate change occurs, it will be of most benefit to have the widest array of genetic diversity in crops and livestock possible. Thousands of varieties and species across the spectrum of edible plants and livestock have been lost in the last century, and more must be done to preserve these varieties and encourage their use and further development (Thrupp, 2000; VanBueren, et al., 2002).

Agricultural biodiversity in time and space increases resilience in a myriad of ways: complementary use of soil nutrients and water, increased total productivity through appropriate polyculture mixtures, decreased risk from one crop failure, pest protection, the creation of microclimates suitable for beneficial insects and strengthening the genetic traits of local landraces. Evidence is beginning to show that "local practices of mixing species and varieties have beneficial effects on crop production over time, especially by buffering climate variability and reducing pest damage" (Tengo and Belfrage, 2004) In case studies in Tanzania and Sweden, practices that increased agrobiodiversity increased diversity in species in and above the soil as well (Tengo and Belfrage, 2004). Agricultural biodiversity provides many environmental services which increase farm resilience. Agricultural biodiversity also affects the dietary quality and variety of the community, as polycultures offer a wide array of crops maturing throughout the season. Nutrient deficiencies and food insecurity pose health risks and reduce people's ability to perform physical labour, let alone cope with drastic changes. Any practice that improves the community's food intake thus makes the population more resilient as well (Thrupp, 2000).

Landscape management in organic agriculture

Organic farms often include diverse landscapes, which require special forms of management, and management techniques in the community as a whole can also benefit the entire ecosystem. No organic farm operates separately from other farms around it and the rest of the ecosystem. Every farm depends on interactions within the ecosystem, and thus we must briefly consider the role OA plays in the resilience of the surrounding environment. Organic standards have requirements in this area, including a prohibition on clearing primary ecosystems and several recommendations to include wildlife refuges and habitat corridors on farms.

The polyculture systems discussed above are a good starting point to discuss landscape management. Some polycultural systems go so far in mimicking natural ecosystems that "agriculture becomes a sequential harvesting system of crops and non-food crops" (Berkes, et al., 2000). Traditional agroforestry often leaves the forest largely intact with gaps to produce crops or promote the growth of wild crops. Understory cropping systems also modify the existing habitat rather than replace it altogether. Shade-grown coffee, for instance, is often grown in this way, though it can also be grown under trees planted for the purpose. All of these systems make organic farms connect more naturally with wilder land around it and cause less habitat disruption than conventional farming would.

For farms with less complex polyculture systems, it is particularly important to examine the fields as a whole. While land unused for production may appear unimportant, these places offer several opportunities to increase biodiversity. Hedgerows and vegetative buffer strips, essentially permanent vegetation such as shrubs and trees on the edges of farms, provide habitat for a variety of creatures and offer corridors between one section of habitat and another. Riparian corridors are also important; planting native vegetation on the edges of streams and irrigation ditches can offer habitat and prevent soil erosion as well. Riparian corridors, ponds, and even wetlands such as rice paddies also provide important habitats for migratory fowl and watering holes for other animals (Scialabba and Williamson, 2004).

Herders must consider their impact on a large area of landscape. Sahelian herders use small-scale movements based on ecosystem feedback. African herders are known to maintain range reserves, areas they do not graze that provide resources in drought years. Such buffers help improve the resilience of the system to disturbance (Berkes, et al., 2000).

Farming communities as a whole may have practices that preserve their surrounding landscapes. Many communities in Southeast Asia and Oceania once had, and some still have, watershed-based management systems. These systems control who takes irrigation water when, thus preventing overdraws, ensuring water for upstream and downstream users, and retaining water for the rest of the ecosystem (Berkes, et al., 2000). Even sacred groves protected by the community, which one would not immediately see as an organic farming practice, offer havens to a variety of species that farms may not, strengthening agroecosystems and the ecosystem as a whole.

Community knowledge systems: millennia of adaptations

Farmers worldwide hold a huge body of information about their farming systems. Farmers have observed phenomena and adapted their farming systems to better suit changing needs. Such practices are particularly seen in the array of crop varieties and livestock breeds developed solely for local use. The risk of global climate change is that changes will accelerate such that farmers will need to observe, learn, and respond more quickly than before. Changes will be faster and more radical, perhaps requiring new means of sharing information. OA is based on ecological processes; knowledge of the agroecosystem is thus a prerequisite to any organic farm. Farmers with a traditional knowledge base stand at an advantage in further developing ecological processes to respond to the effects of climate change.

Organic agriculture recommendation for ecological knowledge

For optimum sustainability of an agro-ecosystem, all activities including crop production, animal husbandry and general environmental maintenance should be organized such that all the elements of the farm activities interact positively. Practical farming skills, based on knowledge, observation and experience are therefore important for organic growers. Careful practice based on skill and knowledge often avoids the requirement for synthetic inputs, and reduces reliance on inputs.

(IFOAM, 2006)

Community knowledge systems to inform organic agriculture

As discussed above, farmers around the world have developed locally-adapted seeds and livestock varieties. Seed varieties developed to assist developing nations often do not succeed in the absence of large amounts of inputs and are less adapted to stress conditions. Locally-adapted varieties are better able to handle difficult climate conditions. Traditional knowledge extends beyond crop and livestock varieties to apply to every aspect of the farming system. Most traditional practices seek to avoid risk and attempt to maximize the use of local resources (Altieri and Nicholls, 2006; Tengo and Belfrage, 2004). Many of the practices designed to improve biodiversity described above, including complex polycultures, rotations and succession management are all based on extensive local knowledge of ecosystems. Monitoring the status of and changes in ecosystems is essential to this process, and keen observations will become yet more important as climate changes (Berkes, et al., 2000). Many communities use wild species as indicators of agroecosystem health (Tengo and Belfrage, 2004).

Specific practices that confer resilience and health to the ecosystem may not be expressed as such, but rather as cultural practices and taboos. Some communities, for instance, protect important beneficial species from being hunted, collected, or disturbed during vulnerable life stages (Tengo and Belfrage, 2004). Communities rely on local institutions and leaders to enforce these rules and also to coordinate appropriate resource use (Berkes, et al., 2004). Sustainability can thus be embedded in the very framework of local culture.

As knowledge tends to be based in communities, not just individuals, farming communities that share information build resilience by finding and disseminating best practices and coping mechanisms more quickly (Tompkins and Adger, 2004). Farmers must transmit information to each other and to the next generation for these systems to survive (Tengo and Belfrage, 2004). Some of the best examples of knowledge transmission actually come from communities that stopped using many of their traditional practices and are now in the process of reviving them. In the central highlands of Mexico, farmers facing severe erosion have created the non-profit group, Vicente Guerrero Group (VGG) to revitalize sustainable practices to improve their soils. VGG trains farmers to teach other farmers best practices, emphasizing that farmers have an obligation to share their knowledge with each other. This group has trained over 2 000 farmers in soil and water conservation practices in Mexico and Latin America (Bennack, et al., 2002). The Indonesian group "Pusspaindo" has instituted extension workers in every participating village. The extension workers are responsible for maintaining audits of natural resources in each village and networking with other extension workers and farmers about problems, such as the potential loss of a local landrace (Scialabba, et al., 2002).

The development of cooperatives for organic marketing has helped facilitate the sharing of organic practices. A different group of Indonesian farmers collaborated with local NGOs and the National Parks of Indonesia to create the Indonesian Cassia Cinnamon Project, a cooperative to gain better access to markets for their organic spices. The cooperative then reinvests in community improvements, and the trees used for spices serve as a buffer habitat for a national park. Nearly 3 000 farmers have joined the cooperative (Scialabba, et al., 2002). In Tabasco, Mexico, farmers joined together to market organic cacao not only grown with traditional methods, but processed in traditional ways as well. This effort has promoted organic methods as well as reforestation, as cocoa plants require shade (Scialabba, et al., 2002). Farmers in both cooperatives have improved their market opportunities, which helps ensure that their practices which increase resilience are also more economically profitable.

As farmers develop more accountability towards each other and their own standards within organizations or marketing groups, they also create support networks to improve and extend organic practices. Community cohesion has proven to be a necessity to decrease certification and marketing costs as a critical mass is developed at all levels, from the cumulative knowledge generated to the quantities of produce grown. Having existing communication systems, coping mechanisms and commitment to ecological principles should also help farmers respond cooperatively and collectively to global climate change, increasing their adaptive capacity as a community.

Community knowledge as a form of adaptive management

Traditional knowledge is not just a system for the present, but a source of institutional memory about what practices have worked best over time. Such knowledge has been described as a "reservoir of adaptations," a whole set of practices that may be used again if the need arises (Tengo and Belfrage, 2004). Likewise, farmers do not just observe, but create their own experiments and trials to improve their techniques. Not every traditional practice is ecologically sound. Some practices may have been useful at one time, but are not appropriate due to new conditions or overuse (Berkes, et al., 2000). Community knowledge thus represents a process of learning as much as a single body of information.

This process of building traditional knowledge has been compared to the scientific approach of adaptive management, so much so that adaptive management has even been described as science's rediscovery of traditional knowledge processes (Berkes, et al., 2000). Adaptive management is different from other modes of scientific inquiry first and foremost because it is based in solving ecological problems, which are often too complex for one to have all the information at the outset but yet also too urgent not to respond (Settle, 2002). Adaptive management requires willingness to try an approach, evaluate it keenly, and modify the approach in an iterative process; in other words, it accepts the inherent uncertainty involved in manipulating whole ecosystems (Berkes, et al., 2000). Rather than attempt to change an aspect of an ecosystem, adaptive management focuses on improving the resilience of the ecosystem as a whole, which is a good basis for using adaptive management to help farmers respond to climate change. Traditional knowledge systems and adaptive management are both by necessity interdisciplinary and include a variety of players (Settle, 2002). These systems involve learning "not at the level of the individual but social learning at the level of societies and institutions" (Berkes, et al., 2000).

There is much to be learned from indigenous organic agricultural practices that can be applicable elsewhere as farmers worldwide respond to global climate change. As scientists study these systems, and increasingly work with farmers to improve them (i.e. participatory research and development), scientists do so on the farmers' own terms. Using adaptive management best resembles farmers' existing means of using observation and trial and error to improve their farming systems. One interesting example of a participatory adaptive management approach is the re-introduction of local pumpkin landraces in Cuba. In response to a shortage of inputs, the Cuban government began several research projects to find alternatives means of production. After trials with conventional seeds (hybrids designed for intensive input use), pumpkin yields decreased significantly. Researchers decided to try local pumpkin landraces instead, involving farmers in growing a wide array of varieties and selecting those that gave the best yields with low inputs. Farmers were able to select genotypes that worked best in their real-world conditions, and these seeds were used to supply other farmers. The project was so successful that Cuba has developed a program called Participatory Plant Breeding for Strengthening Biodiversity with several other crops (Scialabba, et al., 2002).

Looking beyond individual communities, the sum total of ecological knowledge that farmers possess is a vast resource for adapting to climate change. As ecosystems change, innovations adapted to one region may prove very useful elsewhere, and there need to be systems to better share this information (Stigter, et al., 2005). Agricultural scientists should devote research to understanding traditional practices to manage risk and determine how to apply these systems more broadly (Tengo and Belfrage, 2004). Likewise, development practices have often ignored local knowledge and instead recommended completely new agricultural systems reliant on external inputs. In the face of climate change, farmers need development methodologies that "encourage (their) participation, use of traditional knowledge, and adaptation of farm enterprises that fit local needs and socioeconomic and biophysical conditions" (Altieri and Nicholls, 2006).

CONCLUSIONS

OA promotes agroecological resilience, biodiversity, healthy landscape management, and strong community knowledge processes. Improved soil quality and efficient water use strengthen agroecosystems. Practices that enhance biodiversity allow farms to mimic natural ecological processes, which enables them to better respond to change. Farmers must closely observe their agroecosystems and often work with other farmers to share information and learn. As a whole, OA thus builds adaptive capacity on farms.

In order for farmers to take advantage of the resilience OA offers, they must also have access to markets for their goods. The challenges for organic marketing are three-fold in developing countries: certifying farmers, connecting them with existing export markets and developing markets for organic products within developing countries themselves. It is worth noting that many, but not all, traditional agricultural systems are organic by default and would thus meet organic certification standards as they are or with some improvements. Thousands, if not millions, of farmers in this situation could take advantage of organic markets if they had proper access to them. Consumers are increasingly willing to pay a premium for OA, and advertising OA's role in helping farmers adapt adds to the litany of other environmental benefits of this agricultural system. Even where no lucrative markets are available, OA offers opportunities for increased resilience of the farming system and the self-reliance of households.

While this paper has focused on adaptations at the farm and community level, there is much that governments could do to assist farmers in climate change adaptation by creating incentives for OA and promoting organic techniques through agricultural research and extension systems. Governments may also consider funding adaptive management research with farmers on best practices and developing means of disseminating this information. Such research can both improve traditional systems as well as collect information about agricultural practices that will be relevant elsewhere.

Much work will still continue on predicting the effects of climate change, but the vast majority of climate change effects, particularly at the local level, remain unpredictable. Lugo (1995) thus wisely writes, "Management does not require a precise capacity to predict the future, but only a qualitative capacity to devise systems that can absorb and accommodate future events." Combining the best of traditional practices with ecological science holds great potential for furthering the adaptive capacity of OA. There is need to merge the study of global climate change adaptation with the rigorous investigation and improvement of organic practices to determine how farmers may cope best. In particular, there is a need to preserve local landraces of crops and livestock, as well as the specific practices used in raising them, and to disseminate that information. As climate change occurs, farmers may need means of sharing and learning very local practices to further adaptation, locally and globally. When natural principals are used as a guide, farmers can reduce their risks and increase their ability to cope with climate change.

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