Agroecology: key concepts, principles and practices

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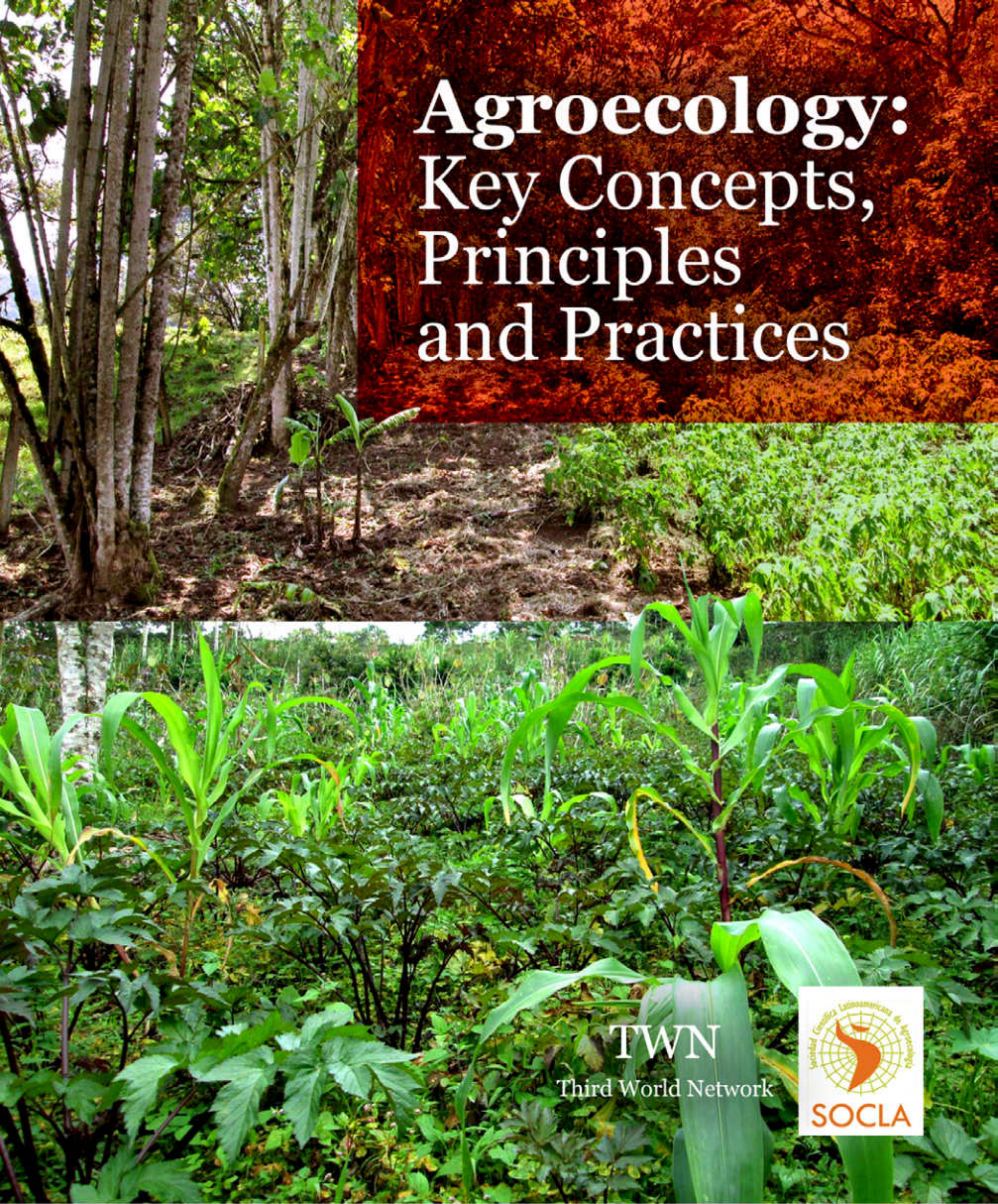
1 author:

Miguel A. Altieri
University of California, Berkeley

Agroecology:
Key Concepts, Principles and Practices



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AGROECOLOGY: KEY CONCEPTS, PRINCIPLES AND PRACTICES

Main Learning Points from Training Courses on Agroecology in Solo, Indonesia (5-9 June 2013) and Lusaka, Zambia (20-24 April 2015)

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BACKGROUND AND INTRODUCTION

THE current challenges to agriculture posed by food insecurity and climate change are serious. There is a paradox of increased food production and growing hunger in the world. The global food production system is broken as we are destroying the very base of agriculture with unsustainable practices. Conventional agriculture has contributed significantly to the crisis including climate change. Meanwhile, the poorest countries will suffer the most from climate change; in particular, small subsistence farmers will be affected.

The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD)[1] concluded that "business as usual is no longer an option" and that the future of agriculture lies in biodiverse, agroecological-based farming that can meet social, economic and environmental goals as well as maintain and increase productivity.

Agroecology is therefore increasingly recognized as the way forward for agriculture, capable of delivering productivity goals without depleting the environment and disempowering communities. Agroecology, which uses ecological concepts and principles for the design and management of sustainable agricultural systems, has consistently proven capable of sustainably increasing the total output of diversified farms and has far greater potential for fighting hunger, particularly during economically and climatically uncertain times.

Recognizing the urgent need for capacity building on agroecology, the Third World Network (TWN) organized two training courses to equip key actors with a comprehensive understanding of the principles and concepts of agroecology and to provide evidence of successes through illustrative examples. The first was a Southeast Asian Training Course on Agroecology, organized together with Aliansi Petani Indonesia (API) in Solo, Indonesia from 5-9 June 2013. The second was a Southern and Eastern African Agroecology Knowledge and Skills Sharing, organized with the African Centre for Biodiversity (ACB), in collaboration with the Kasisi Agricultural Training Centre, in Lusaka, Zambia from 20-24 April 2015.

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1 IAASTD (2009). *Agriculture at a Crossroads. International Assessment of Agricultural Knowledge, Science and Technology for Development*. Island Press, Washington, DC. http://www.agassessment.org

The training courses covered the following topics:

- Agroecology and the planetary food, energy, economic and social crises
- Principles and concepts of agroecology: The scientific basis
- The ecological role of biodiversity in agroecosystems
- Biodiversity and insect pest management
- Soil ecology and management
- Ecological basis of disease and weed management
- Agroecological basis for the conversion to organic farming
- Agroecology, small farm development and food sovereignty
- Agroecology and resiliency to climate change

The resource persons were Prof. Miguel Altieri and Dr. Clara Nicholls, from the University of California, Berkeley, USA and the Latin American Scientific Society of Agroecology (SOCLA). Participants at both courses included farmers and farmer leaders, representatives of farmers' organizations and civil society organizations working on agroecology/ecological agriculture, as well as government officials.

This document is a summary compiled by TWN staff of the main learning points from the lectures given during the training courses, serving as a useful resource booklet on the key concepts, principles and practices of agroecology. Miguel Altieri provided valuable inputs.

Chapter One

THE CRISIS OF INDUSTRIAL AGRICULTURE

THE planet is facing multiple inter-related crises: economic, financial, energy, ecological and social. Climate change represents only one dimension of the ecological crisis. These crises do not evolve randomly but are a result of a dominant and exploitative capitalist system that promotes economic growth at the expense of people, nature and planet. We cannot continue with the same approach, as nature has her own tipping points and boundaries and if these are breached, the whole world is threatened.

With this kind of development, there are different spikes (representing large increases) in different measurements such as population and associated consumption. However, it must be clear that not all populations have the same consumption patterns. For example, one per cent of the population controls 80 per cent of the wealth and the other 99 per cent control the remaining 20 per cent of wealth. Similarly, with regard to climate change, there is a spike in carbon dioxide emissions, but one person in the United States (US) or Europe could be responsible for 20 times as much carbon dioxide emissions as a small farmer in Asia or Africa.

There is also an extinction spike – we are losing thousands of species daily. Each organism plays an important ecological role and we do not yet have full knowledge on the implications of such losses. Our natural systems are under stress due to deforestation, soil erosion, climate change and other factors, all associated with a globalized economy. Environmental problems are linked to socio-economic problems such as poverty, hunger, inequity and ecological refugees. Agriculture is the sector where all these issues converge.

Agriculture is the artificialization or simplification of nature. When we have monocultures, we need to start to apply external inputs and increase management intensity, because monocultures lack biological diversity, which plays key ecological roles. Monocultures can be conventional or even organic, which would still require inputs, where botanical pesticides substitute for chemical pesticides. In a natural forest, there is no need for these interventions, because all the organisms interact to form a self-regulating system.

Unfortunately, 90 per cent of the world's 1.5 billion hectares under agriculture is dominated by industrial monocultures that are highly dependent on external inputs and energy. The world is largely dependent on only 12 types of grains and 23 species of vegetables. Yet, these monocultures are extremely vulnerable to pests, diseases and climate change and have contributed to the great famines in history, for example, in Ireland and India, where genetically homogeneous agriculture failed.

The advance of industrial agriculture arose with the Green Revolution in the 1960s. The North created international agricultural research centres with temperate-region scientists to 'teach' farmers in the tropics to do agriculture. Science became an instrument of those in power. Agricultural projects were funded to fit a particular political agenda and promoted uniform so-called high-yielding varieties at the expense of local crop varieties.

The Green Revolution first took off in Mexico and then spread to India and other regions. The technologies were not scale-neutral but favoured large-scale farmers. All over the world today, this model is still prevalent. The number of farms is decreasing while the size of farms is increasing. There has however been a tremendous erosion of genetic diversity. Industrial farming has replaced many natural, diversified farming systems.

Monocultures may have temporary economic advantages but in the long run do not represent ecologically optimal systems. Most major crops are genetically uniform and very vulnerable to pests and disease (as well as climate variability). This has given rise to an addiction to pesticides. Chemical pesticides do not work eventually because insects and weeds develop resistance, so we have to develop new pesticides and apply more; this is called the "pesticide treadmill". Moreover, the law of diminishing returns has shown that yields decrease after hitting a peak with the further application of synthetic fertilizers.

The Green Revolution was based on three assumptions: that there would always be abundant and cheap energy; the climate would be stable and unchanging; and water would always be available. All of these assumptions are not valid today.

Soil carbon losses are highest where industrial farms are and industrial agriculture is a major contributor to climate change, emitting 17-32 per cent of greenhouse gas emissions, in the form of carbon dioxide, methane and nitrous oxide. There are in turn many effects of climate change on agriculture, including the loss of biodiversity and lowered yields. In 2012, the US Midwest experienced its worst drought in 30 years and farmers lost 30 per cent of their corn and soybean harvest. So, industrial monoculture systems are not resilient, but are vulnerable to climate change.

Globally, agriculture uses 12 per cent of the land base but 70 per cent of all water withdrawn. We do not have enough water to maintain our current consumption levels; for example, the beef industry uses 15,000 litres of water per kg while cereals use 1,500 l/kg and fruits, 1,000 l/kg.

There are now dead zones in the oceans due to eutrophication. The main contributors are nitrogen and phosphorus agricultural inputs that have leached into rivers, ending up in the ocean. They promote algae growth, which in turn sucks up all the oxygen.

The bottom line is that industrial agriculture is simply not feeding the world as it was heralded to. To produce only 30 per cent of the food we eat, it uses 70-80 per cent of arable land, 70 per cent of the water, and 80 per cent of the fossil fuels used in agriculture. Industrial agriculture actually produces more biofuel and fodder than food. Global hunger is meanwhile on the rise. Half the world's population are not fed well; 3.4 billion suffer hunger, malnutrition, and obesity. About 33-40 per cent of the food produced in agroindustrial chains is wasted in production, transport or thrown away. About 40 per cent of our global grain supply feeds animals.

Hunger is therefore less related to production and more to poverty and inequality. The root cause of hunger, however, is that the food system is controlled by a small group of multinational corporations. In 2008, food prices hit an all-time high because of market speculation, which led to people not being able to afford food. Yet, top corporations like Cargill and Bunge earned record profits at this time. This food empire controls the food to be produced, the technologies to be used, the food quality and quantity that consumers will eat, and the price they will pay for it. Both consumers and producers are victims of this globalized food system. Today, the productivist discourse continues. The aim is to double food production by 2030. And the new magic bullets being promoted are genetically engineered or modified (GE/GM) crops.

It is important to note that the corporate food empire is closely linked with other industries; there is an agroindustrial convergence with car and petroleum companies, where the drive now is to produce agrofuels. Seventeen countries use 50 per cent of the world's energy while the other 175 countries use the other half. However, oil resources are running out. About 25 million ha representing two per cent of cropland are being used for agrofuel production. South America, Africa and Asia are providing the land to grow agrofuels. As a result, land grabbing is rampant. As of 2010, 140 million acres of land had been grabbed, 75 per cent of which was in Sub-Saharan Africa. Land grabs and the incidence of serious hunger are positively correlated.

Associated with agrofuels are GE crops. There are more than 180 million hectares under GE crops. The top four GE crops are soybean (65 per cent of global acreage), corn, cotton and canola. These are channelled largely for agrofuels, animal feed or cash crops. So although companies are saying that we need GE crops to feed the hungry, there is no evidence to show that GE crops are indeed doing so. They are also not solving environmental problems. Herbicide-tolerant soy makes up the bulk of GE crops grown. In the US, Argentina, Paraguay and Brazil, soybean volunteers and weeds resistant to glyphosate have sprung up, so more toxic herbicides are now being applied.

Golden Rice, genetically engineered to be nutritionally enhanced with Vitamin A, is promoted to address Vitamin A deficiency. One of the reasons for this deficiency in rural areas is the destruction of biodiversity in traditional rice farms, which had previously provided a balanced diet. Leafy vegetables, cassava, mangoes and other fruits provide more Vitamin A than Golden Rice. Furthermore, farmers who plant rice in an integrated manner with ducks, fish, and so on, provide enough Vitamin A and other nutrients. We therefore need to restore agricultural diversity (at genetic and species levels) – not only plant diversity, but also culinary diversity and curative diversity – in the fields.

There are also externalities associated with agriculture, such as adverse health and environmental impacts. This means that the current cost of food is actually higher when we account for greenhouse gas emissions, water contamination, loss of biodiversity, soil losses, public health impacts and other externalities. In the UK, the price tag of industrial agriculture's externalities is about £205 per hectare.

The agricultural challenge then, for the coming decades, is to increase food production substantially and sustainably, using the same arable land base with less petroleum, water and nitrogen within a scenario of climate change, social unrest and financial crisis. We need to rethink agricultural systems and we need a totally new paradigm. That future agricultural system must be de-coupled from fossil fuel dependence, be nature-friendly and have low environmental impacts, serve multiple functions, be resilient to climate change and other shocks, and be a foundation for local food systems, including indigenous and local innovations.

We are thus looking for systems that have high productivity, efficiency, and biodiversity with high recycling rates, use low external inputs, are resilient and efficient in use of local resources, and have a high level of synergy and integration. These new systems are based on agroecology. It is the way to bypass the corporate food empire.

Agroecology is the application of the science of ecology to agricultural systems. It therefore seeks to develop an ecological structure that does not need external inputs and which allows the necessary interaction among species for the system to work. For example, an ecological farm that is surrounded by a forest will receive many services from the forest, such as beneficial insects and enhanced soil organic matter. This is in stark contrast with, for example, a cotton plantation where only cotton plants are present which need constant external energy subsidies.

Conventional agriculture simplifies nature as it involves a change from natural ecosystems to monocultures (see Box 1). There are significant differences between agricultural ecosystems and natural ecosystems; for example, the former have low genetic diversity and open mineral cycles whereas the latter have high genetic diversity and closed mineral cycles. The inherent strengths of a natural ecosystem are: inter-dependency, self-regulation, self-renewal, self-sufficiency, efficiency and diversity. When we move to monocultures, the system loses these strengths and is simplified, thereby requiring external inputs. Agroecology, on the other hand, mimics and rebuilds in agroecosystems strengths inherent to the natural ecosystem.

Box 1: Schools of thought influencing conventional agriculture

THE conventional system of agriculture came about due to the influence of four schools of thought. The first (arising from De Cartes) was to break up the whole and study the different parts in detail; scientists and agronomists would then specialize. However, this ignores the need for a science that integrates everything and looks at the system in a systemic, holistic way.

The second approach emerged when Darwin introduced the concept of the survival of the fittest. However, he failed to see there is much more cooperation and interaction in nature than competition. His theories influenced biologists and economists to focus on competition.

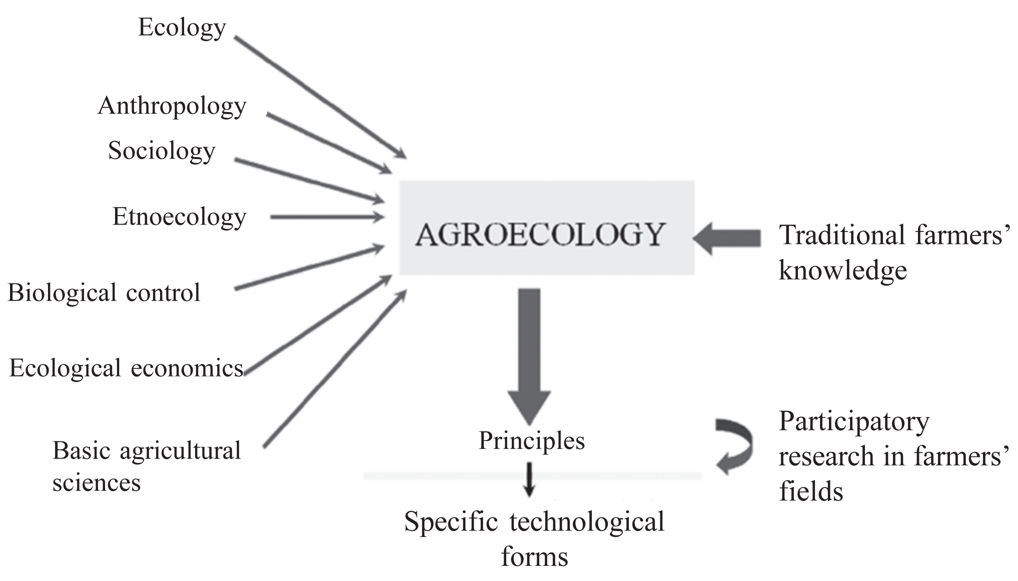
The third approach is based upon von Leibeig's theory that there will always be a factor that will limit productivity, so in order to reach optimal productivity one must overcome the limiting factor. Therefore, for example, if your limiting factor is nitrogen, you have to add nitrogen; if the limiting factor is a pest, then you have to remove the pest. However, this approach ignores the fact that the limiting factors are symptoms of a deep ecological dysfunction and that attacking the symptoms only creates more problems. When we control one limiting factor, another arises. With chemical inputs, yields increase up to a point and then decrease. For example, yields do not increase at the same rate as applying nitrogen fertilizer. Conventional agriculture concludes that it is the variety that is not being responsive and thus, a new variety is needed. However, yields decrease because of too much chemical fertilizer in the soil, which makes it acidic. This in turn affects microbial communities and availability of other nutrients in the soil. Also, when we apply chemical fertilizer, it is very soluble and the nitrogen that is absorbed by the plant cannot be metabolized into protein and amino acids. The free nitrogen in the foliage attracts and stimulates insect pests such as aphids that use nitrogen for reproduction. Agroecology, on the other hand, examines the root cause of the problem instead of addressing the symptoms. In this case, using legumes to put nitrogen into the soil would be a better alternative, as the nitrogen is slowly released and does not lead to nitrogen accumulation in the foliage. Many researchers have found that increases in fecundity and developmental rates of aphids are highly correlated with increased levels of soluble nitrogen in leaf tissue. The idea that chemical nitrogen fertilizer inhibits protein synthesis, making plants more susceptible to pests and diseases, was advanced by French scientist F. Chabboussau in the 1960s.

The fourth approach was based on Malthus who theorized that the gap between population growth and food productivity is hunger and the solution is to produce more food. Malthus had a big influence on the Green Revolution, which focused on increasing productivity through yields, above all else. Thus conventional agriculture is obsessed with closing the "yield gaps" between production that highly subsidized farms obtain in the North and that of poor farmers in the South.

Agroecology is a science, a practice and a movement. It is based on scientific and traditional knowledge (Figure 1). It is a science that bridges ecological and socio-economic aspects. It can work at various levels – farm, community, national, regional, and so on. Biological processes are enhanced using agroecological principles and these principles can be shared via farmer-to-farmer exchanges.

Agroecology needs to be built from the bottom up, especially through social movements in rural areas. There is a need to create alliances between rural and urban communities. Agroecology is a pillar of the food sovereignty framework which promotes the provision of land, water, seeds and other productive resources to small farmers and landless people, along with economic opportunities.

Figure 1. Agroecology combines elements of traditional farmers' knowledge with elements of modern ecological, social and agronomic science, creating a dialogue of wisdoms from which principles for designing and managing biodiverse and resilient farms are derived



Chapter Two

CONCEPTS AND PRINCIPLES OF AGROECOLOGY

2.1 Principles

AGROECOLOGY is a science that draws on social, biological and agricultural sciences and integrates these with traditional knowledge and farmers' knowledge. This gives rise to basic principles that materialize in specific technological forms. At the heart of the agroecology strategy is the idea that an agroecosystem should mimic the functioning of local ecosystems, thus exhibiting tight nutrient cycling, complex structure and enhanced biodiversity. The expectation is that such agricultural mimics, like their natural models, can be productive, pest-resistant and conservative of nutrients. Learning from nature allows development of agroecosystems with a minimum dependency on agrochemical inputs and energy, emphasizing interactions and synergisms among the many biological components of agroecosystems to enhance recycling and biological control, thus improving overall ecological efficiency and environmental protection.

A key agroecological strategy in designing a sustainable agriculture is to reincorporate diversity into the agricultural fields and surrounding landscapes. Diversification at the field level occurs as variety mixtures, rotations, polycultures, agroforestry, crop-livestock integration, etc., and at the landscape level in the form of hedgerows, corridors, etc., giving farmers a wide variety of options to assemble spatial and temporal combinations. Emergent ecological properties develop in diversified agroecosystems, which allow the system to function in ways that maintain soil fertility, crop production and pest regulation. Agroecological management practices that increase agroecosystem diversity and complexity act as the foundation for soil quality, plant health and crop productivity.

Agroecology has its roots in ecology, applying the understanding of natural ecosystems and comparing these to mechanized agroecosystems. There are six principles of ecology:

- Networks: nature is a network of living systems nesting within other living systems that are interconnected.

- Cycles: matter cycles continually through the web of life, hence ecosystems do not generate waste.
- Solar energy: this is the fundamental source of energy that drives all ecological cycles. (This is why agroecology gives emphasis to plant diversity as plants transform solar energy into chemical energy which drives all other networks and food webs.)
- Partnership: exchanges of energy and resources in an ecosystem are sustained by pervasive cooperation, not competition. (The challenge then is to design synergistic systems.)
- Diversity: all ecosystems derive stability and resilience through the richness of diversity.
- Dynamic balance: an ecosystem is a flexible, ever-fluctuating network.

Borrowing from the above principles, the design of farming systems based on agroecology is based on the application of the following five principles:

- Enhance recycling of biomass, optimizing nutrient availability and balancing nutrient flow.
- Secure favourable soil conditions for plant growth, particularly by managing organic matter and enhancing soil biotic activity.
- Minimize losses due to flows of solar radiation, air and water by way of microclimate management, water harvesting and soil management through increased soil cover.
- Species and genetic diversification of the agroecosystem in time and space at the field and landscape levels.
- Enhance beneficial biological interactions and synergisms among agrobiodiversity components, thus resulting in the promotion of key ecological processes and services.

Agroecological principles take technological forms or practices in order to be applied. For example, the principle of diversification in space and time at the farm level takes, in practice, the form of polycultures. These practices promote processes that are fundamental for an agroecosystem to function, such as nutrient cycling, pest regulation, and allelopathy for weed control. If we want to know how agroecology works, we then use indicators like soil quality and plant health, which allow us to take the pulse of a system and see if the principles are being correctly applied.

Appropriate technologies should be based on indigenous knowledge and rationale; be economically viable, accessible and based on local resources; be environmentally sound and socially, culturally and gender sensitive; be risk-averse and adapted to heterogeneous circumstances; and enhance total farm productivity and stability. There should no longer be a top-down approach with farmers as passive recipients of information, but farmers should exchange information within farmer networks, supported by organizations ready to commit to the agenda of farmers.

2.2 Agroecological practices and systems

The tendency of nature is to move towards complexity; however, with industrial agriculture a chemical 'wall' is applied to maintain monocultures and simple systems. Agroecology designs complex agroecosystems, accompanying nature in its tendency towards complexity. There are many strategies for agroecosystem diversification, such as crop rotations, cover cropping, crop-livestock mixtures, agroforestry, polycultures and intercropping, multi-lines and variety mixtures (genetic diversification), field crop border diversification and corridors linking fields and natural vegetation. All these agroecological practices restore vegetational diversity in agricultural fields and surrounding landscapes, giving farmers a wide variety of options to assemble spatial and temporal plant-animal combinations.

The main goal of designing a diversified farming system is the enhancement and maintenance of agrobiodiversity as a strategy for provisioning ecological services which emerge from beneficial ecological interactions among crops, animals and soils deployed in the farms. By strengthening the weak ecological functions in the agroecosystem, farmers first reduce and substitute external with internal inputs. Farmers gradually eliminate inputs altogether by redesigning the farm system to rely primarily on ecosystem functions. Emergent ecological properties develop in diversified farms, allowing the system to provide for its own soil quality and fertility, pest regulation and total farm production.

There are many agroecological management practices that increase agroecosystem diversity and complexity as the foundation for soil quality, plant health, and crop productivity. In agroecology the emphasis is on diversifying and strengthening the agroecosystem by adding regenerative components such as combining crops in intercrops, animals and trees in agrosilvopastoral systems, using legumes as cover crops or in rotations or raising fish in rice paddies (see Box 2).

More and more benefits emerge as biodiversity increases in agroecosystems: there will be more beneficial interactions, better resource use efficiency, higher associational resistance to invaders and increased nutrient cycling. Farmer-designed diversity should result in improved biotic diversity and abiotic (soil, microclimate, etc.) conditions, which in turn will lead to good system qualities or ecological processes characteristic of healthy and productive farms. A farm can provide for its own soil fertility, its own pest regulation, and so on, just by imitating the way nature functions, allowing for interactions to occur between the different soil, plant and animal components. Figure 2 shows a diversified rice paddy

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, resulting 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.

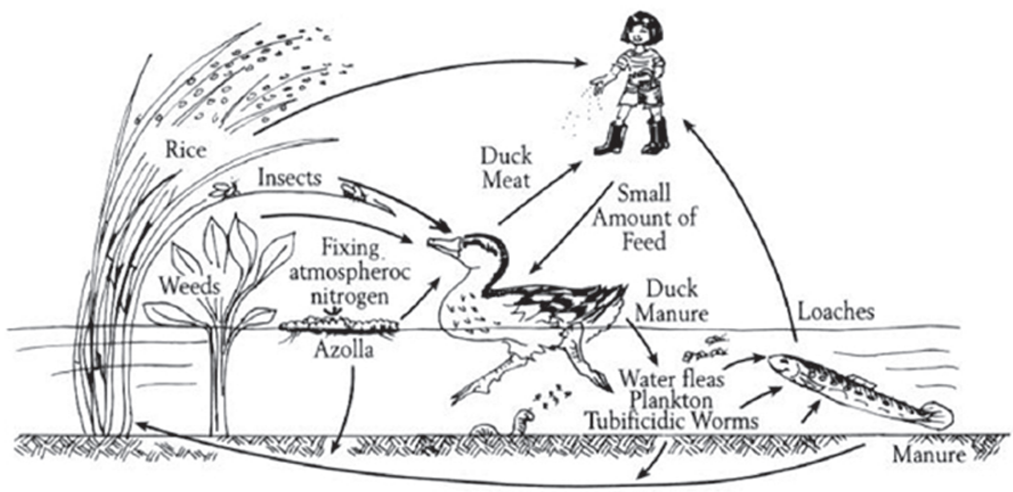
Cover crops and mulching: The use of pure or mixed stands of grass-legumes, e.g., under fruit trees, can reduce erosion and provide nutrients to the soil and enhance biological control of pests. Flattening cover crop mixtures on the soil surface in conservation farming is a strategy to reduce soil erosion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

Green manures are fast-growing plants sown to cover bare soil. Their foliage smothers weeds and their roots prevent soil erosion. When dug into the ground while still green, they return valuable nutrients to the soil and improve soil structure.

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.

system where the interactions of rice, weeds, insects, fish and ducks promote key processes (nutrient cycling, pest control, etc.), allowing the rice system to function without need of external inputs.

Figure 2. Interactions of various agrobiodiversity components in a rice paddy resulting in processes such as nutrient cycling and pest regulation vital for the productivity of the system



Agreocology can be carried out at different scales/levels: plot, field, and landscape (including surrounding plots and matrices of vegetation surrounding the system). The plots could be used for experiments, the results of which can be then brought onto real farms where other elements of the landscape will add additional complexities to the system. Agroecology principles (in terms of design) can be applied at the large farm level, but the social and political aspects need to be critically discussed. In any case, large farms also need to transition towards being more sustainable.

2.3 Agroecology and traditional farmers' knowledge

The evolution of agroecosystems is a result of interactions between social and ecological systems. We need to understand how people have designed the systems and what knowledge has nurtured the management of these systems. Agricultural systems are the product of the co-evolution and interaction over centuries between nature and society. The more harmonious the interaction, the better the resulting agricultural system. For example, the *waru waru* system in the Andean region was revived over hundreds of hectares to overcome the problem of frost in the highlands. The raised beds surrounded by water allow farmers to grow crops in the midst of frost at 4,000 m above sea level as the water absorbs heat in the day, and releases heat at night. In many places, crop species and genetic diversity are dependent on cultural diversity and thus agrobiodiversity is maintained through cultural traditions.

Agroecological systems are deeply rooted in the ecological rationale of traditional small-scale farmers who for centuries have developed farming systems, many of which offer promising sustainability models as these systems promote biodiversity, thrive without agrochemicals, and sustain year-round yields meeting local food needs. The evolution of these systems has been nourished by complex forms of traditional knowledge about vegetation, animals, soils, etc. within a certain geographical and cultural area. Rural knowledge is based on observation and on experimental learning. Successful adaptations are passed from generation to generation, and historically, successful innovations have been widely shared with members of the community.

Agroecological innovations are born *in situ* with the participation of farmers in a peer-to-peer or horizontal (not top-down) manner and technologies are not standardized but rather flexible and respond and adapt to each particular situation. Undoubtedly, the ensemble of traditional crop management practices represents a rich resource for agroecologists seeking to create novel agroecosystems well adapted to the local agroecological and socioeconomic circumstances of smallholders. There are several benefits and contributions that can emerge from the correct retrieval and use of traditional ecological knowledge:

- detailed local knowledge of productive resources and environment (soils, plants, rainfall conditions, etc.);
- time-tested, in-depth knowledge of the local area as an essential part of any agroecological intervention;
- identification of best farmer practices for dissemination to other farmers and areas;
- use of locally adapted crop varieties and animal species;
- criteria for technology development considering local goals and priorities, gender preferences, etc.; and
- a basis for testing new technologies and their ‘rightness-of-fit’ to local systems and circumstances.

Farmers have a deep knowledge of the ecosystem as they live within it and interact with nature. In many instances, this knowledge has been eroded and lost. In any case, instead of imposing Western science and values on them, we should create a dialogue of wisdoms. At the same time, we cannot romanticize traditional knowledge. With climate change, conditions are changing and farmers may not be able to deal with new challenges with just traditional knowledge. Agroecological approaches combined with traditional approaches would facilitate the optimization of systems and build resilience.

2.4 Agroecology and rural social movements

Agroecology is not a neutral science; it is tied to the concept of food sovereignty advanced by the international peasants' movement, La Via Campesina. It aims to make farmers autonomous and self-sufficient, i.e., to allow people to define their own models of development. Agroecology plays a central role in rural social movements struggling to adopt agroecological farming as an alternative to the destructive practices and unhealthy food produced by industrial agriculture. In the defence and/or conquest of material territory, e.g., through land occupations or policy victories in favour of land redistribution, peasants adopt agroecological farming as part of (re)configuring peasant or family farm territories.

For peasants and family farmers and their movements, agroecology helps build autonomy from unfavourable markets and policies, and helps them restore degraded soils and the productive capacity of their farms and communities.

Through social processes and farmer-to-farmer methods (horizontal exchange of ideas and innovations) rural movements are helping to bring agroecological alternatives to an unprecedented scale.

Agroecology is compatible with the rationale of peasants and conforms to a key technological strategy in their food sovereignty framework due to several reasons:

- Agroecology provides methodologies that allow the development of technologies closely tailored to the needs and circumstances of specific peasant communities.
- Agroecological techniques and designs are socially activating since they require a high level of popular participation.
- Agroecological techniques are culturally compatible since they do not question peasants' rationale, but actually build upon traditional farming knowledge, combining it with elements of modern agricultural science.
- Practices are ecologically sound since they do not attempt to radically modify or transform the peasant ecosystem, but rather to identify management elements that, once incorporated, lead to optimization of the production unit.
- Agroecological approaches are economically viable and break technological dependence by emphasizing local resources and inputs.

The factors needed to support agroecology include enabling policies, fair markets, extension, participatory research, and farmer-to-farmer exchanges. The end result should be a new, biodiverse, organic agriculture which is community- or family-based, is biologically and culturally diverse, is small- to medium-scale, and provides a strong linkage between consumers and farmers.

Agroecology is highly knowledge-intensive, and is based on techniques that are not delivered top-down but developed on the basis of farmers' knowledge and experimentation. For this reason agroecology emphasizes the capability of local communities to experiment, evaluate, and scale up innovations through farmer-to-farmer research and grassroots extension approaches. Technological approaches emphasizing diversity, synergy, recycling and integration, and social processes that value community involvement, point to the fact that human resource development is the cornerstone of any strategy aimed at increasing options for rural people and especially resource-poor farmers. Agroecology promotes community-oriented approaches that look after the subsistence needs of its members, emphasize self-reliance and also privilege local provisioning for local markets that shortens the circuits of food production and consumption.

The expansion of agroecology in Latin America and other regions has initiated an interesting process of cognitive, technological and socio-political innovation, intimately linked to the new political scenarios such as the emergence of progressive governments and resistance movements of peasants and indigenous people. Thus the new agroecological scientific and technological paradigm is being built in constant reciprocity with social movements and political processes.

Agroecology is not neutral and is self-reflexive, giving rise to a critique of the conventional-industrial agricultural paradigm. The technological dimension of the agroecological revolution emerges from the fact that contrary to Green Revolution and other intensification approaches that emphasized seed-chemical packages and 'magic bullet' recipes, agroecology works with principles that take multiple technological forms according to the local socio-economic needs of farmers and their biophysical circumstances. Agroecological innovations are developed with the participation of farmers in a horizontal manner; the flexible nature of the technologies allows them to respond and adapt to the specific circumstances prevailing.

Chapter Three

THE ROLE OF BIODIVERSITY IN ECOLOGICAL AGRICULTURE

BIODIVERSITY is one of the key components that agroecology tries to optimize and use. Biodiversity refers to the variety of life on earth – plants, animals, microbes, the genes they contain, the ecosystems they form, and the interactions between life forms and the environment. When ecosystems are diverse, there are many pathways for ecological processes, so if one is damaged or destroyed, an alternative pathway can be used. Therefore, if native biological diversity is diminished, the functioning of ecosystems is also put at risk. There are many types of biological resources tied to agriculture such as genetic resources, edible plants and crops, livestock, soil organisms, wild resources and naturally occurring insects, bacteria, and fungi. Functional biodiversity includes those organisms that provide key processes, and that through their interactions can, for example, contribute to nutrient cycling, biological regulation and increased productivity.

There are many mechanisms of biodiversity loss such as habitat destruction and fragmentation; the displacement of native varieties by introduced modern varieties; pollution of soil, water and air; climate change; and industrial agriculture and forest plantations. The main cause of genetic erosion in crops is the Green Revolution, which imposed high-yielding but uniform varieties. Along with all this, indigenous and traditional knowledge, which has conserved biodiversity, has further been devalued and lost.

Agroecology exploits not only a variety of crops and animals, but also the many ways by which farmers exploit biological diversity to produce and manage agroecosystems. Higher diversity within the cropping system leads to higher diversity in associated biota. In turn, this leads to more effective natural pest control and pollination, and tighter nutrient recycling as well as more stable and resilient systems.

The types of diversity that can be present in an agroecosystem are:

- species diversity (number of different species in the agroecosystem);
- vertical diversity (number of different levels and strata, e.g., in agroforestry systems, trees play important roles in providing nutrients via leaves, and as barriers to winds, hurricanes etc.);

- genetic diversity (degree of variability of genetic information in the agroecosystem (within and between species));
- functional diversity (the complexity of interactions, energy flow and recycling of materials between the components of the agroecosystem, e.g., in a maize-bean-squash polyculture, each crop has different functions (see Box 3));
- temporal diversity (degree of heterogeneity of cyclical changes in the agroecosystem, e.g., seasonal crops such as cover crops that are planted in spring and incorporated in winter to provide nutrients to the soil or to enhance soil structure).

Box 3: The maize-bean-squash system

Three seeds of maize and three seeds of bean are planted together, with squash planted in between seeding points. The bean grows up with the maize and is a legume that fixes nitrogen into the soil. Maize flowers attract beneficial insects while squash leaches allelopathic chemicals that deter weeds. The system thus provides important processes – pest regulation and nutrient cycling – and is also good for controlling erosion. In the dry season, clover seeds are planted after the maize, bean and squash are harvested. The clover will be a source of fodder for the animals. The clover has very deep roots and can withstand dry conditions. After the animals eat the clover, they will leave behind a lot of manure for the next planting season.

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. 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, affecting their capacity to respond to changes and to generate ecosystem services. Two categories of diversity can be distinguished in agroecosytems: functional and response diversity. Functional diversity refers to the variety of organisms and the ecosystem services they provide for the system to continue performing. 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. Many researchers have found that maintenance of diverse traditional crop varieties (maize, potatoes, rice) is essential for adaptation and survival by poor farmers. Even when planted alongside modern crops, traditional crop varieties are still conserved, providing a contingency when conditions are not favourable.

Biodiversity enhances the performance and function of farms because different species or genotypes perform slightly different functions and therefore have different niches. In general there are many more species than there are 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 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.

There are many advantages of diversity including: less impact of pests, diversification of production, and major species conservation. In addition, polycultures have proven to be more productive than monocultures when productivity is calculated in the form of land equivalent ratio (LER) (see Box 4).

Box 4: Land equivalent ratio

$$\text{Land equivalent ratio} = \frac{\text{Yield of corn in polyculture}}{\text{Yield of corn in monoculture}} + \frac{\text{Yield of bean in polyculture}}{\text{Yield of bean in monoculture}}$$

If the value is 1 or more than 1, it means that the polyculture over-yields. For example, if the LER is 1.5, this means that you need 1.5 ha of land grown under monoculture to get the same yield as 1 ha under the polyculture.

Crop genetic diversity comprises traditional varieties, modern cultivars and crop wild relatives and other wild plant species that can be used. In Latin America, there is a wide range of traditional varieties of maize while in Asia, the same occurs for rice. In the Andes, there are also thousands of varieties of potatoes. Modern varieties can yield more, but demand more water and more fertilizer. So if we calculate productivity with respect to water and fertilizer use, we find that traditional varieties perform much better when there is no water or fertilizer. Diseases also increase when there are fewer varieties of species as the crops are then more susceptible. Mixing varieties is a good strategy to reduce crop diseases.

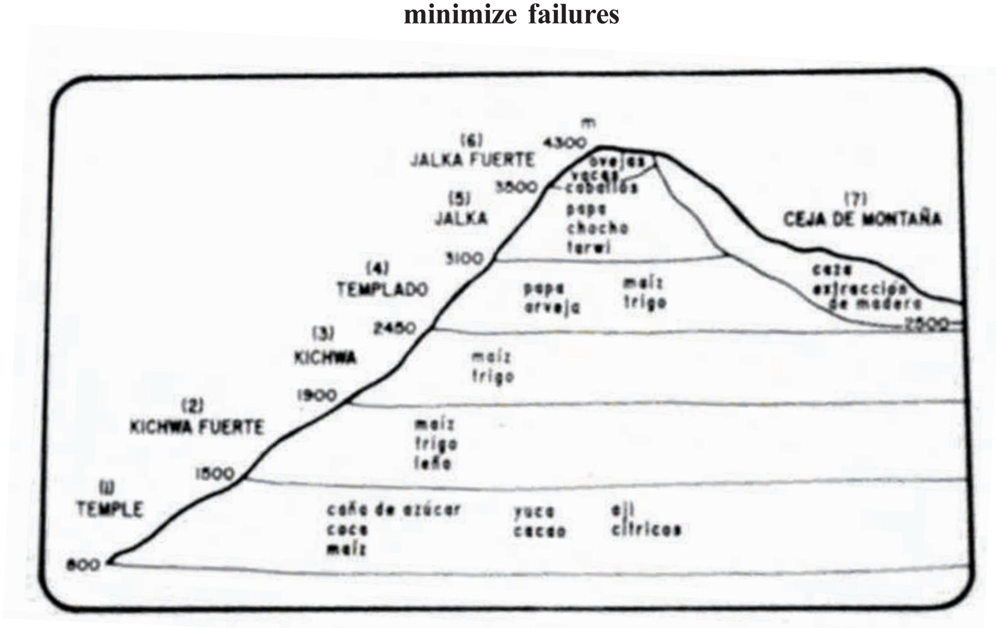
Genetic diversity is closely connected to cultural diversity. The regions with more biodiversity are the ones with more indigenous peoples who maintain traditional varieties as part of their culture. Many of these varieties are disease-resistant and drought-tolerant varieties that perform stably in marginal conditions. Seed exchange underpins this farmer-managed seed system. There are numerous practices for enhancing biodiversity that are tied to rich cultural diversity and local knowledge. For example, in an island in Chile, women have kept traditional varieties of potato as they give potatoes to their daughters when they get married. Rural women are particularly knowledgeable about diverse plant and tree species and their uses for healthcare, fuel, fodder and food.

It is also very important to maintain landscape diversity. Examples of landscape diversity are the *chinampas* in Mexico, the *waru waru* in Peru and the rice terraces in Asia, all of which illustrate a deep knowledge of biodiversity and its interactions. In the Andes, farmers have plots at different altitudinal belts with diversified crops. More plots dispersed along the mountain means lower risk (Figure 3). The community manages the landscape/territory together and follows long-established traditions, such as practising a 7-year rotation.

Soil diversity is also critical. This comprises micro-organisms, micro-fauna (protozoa and nematodes), meso-fauna (acari and springtails), macro-fauna (earthworms and termites) and plant roots which interact with one another and with other plants and animals in the ecosystem. The soil biota maintain soil health, control pests and diseases, perform ecosystem functions such as decomposition and recycling, and maintain production. Earthworms improve the soil's structure by regulating water infiltration and improving root growth. Arthropods improve the soil structure with the creation of faecal pellets, which stimulate microbial activity and ensure a healthy soil food web. Meanwhile, fungi decompose carbon compounds, improve the accumulation of organic matter, retain nutrients in fungal biomass, bind soil particles, improve plant growth, compete with pathogens and decompose certain types of pollutants. Bacteria decompose organic matter, enhance soil structure, compete with disease-causing organisms, and filter and degrade pollutants. Management strategies to enhance soil biodiversity include no-tillage farming, crop rotations, minimal ploughing, mulching, return of plant residues as green manures to the soils, supply of organic matter such as compost, enhanced plant diversity, and the protection of the habitat for soil organisms.

Many traditional and organic farmers add large quantities of organic materials on a regular basis 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 improves the soil's water retention capacity, enhancing drought tolerance by crops, as well as improves infiltration, diminishing runoff and avoiding the transportation of soil particles with water under intense rains. Soil organic matter also improves surface soil aggregation, holding the soil particles tightly during rain or windstorms. Stable soil aggregates resist movement by wind or water. 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

Figure 3. Andean farmers divide the mountain into various altitudinal belts. Crops and varieties are deployed according to their adaptation to changing temperature with altitude, and farmers manage various plots distributed along the slope to minimize failures



Ecogeographical units recognized by *campesinos* in Uchucmarca, Peru

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. 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.

In summary, at the agro-landscape or farm level, there should be species and genetic diversity, with surrounding forest resource biodiversity, insect biodiversity, soil organism biodiversity, plant and animal genetic diversity, habitat diversity, and the related diversities of culture and knowledge.

Chapter Four

ENHANCING PLANT BIODIVERSITY FOR ECOLOGICAL PEST MANAGEMENT IN AGROECOSYSTEMS

INTENSIVE agriculture has displaced many ecosystem services provided by natural ecosystems, with many negative externalities such as pollution and salinization. We can, however, restore ecosystem functions at the plot, field and landscape levels by using polycultures, insectary strips, crop rotation, crop borders, riparian corridors, nature reserves, and so on.

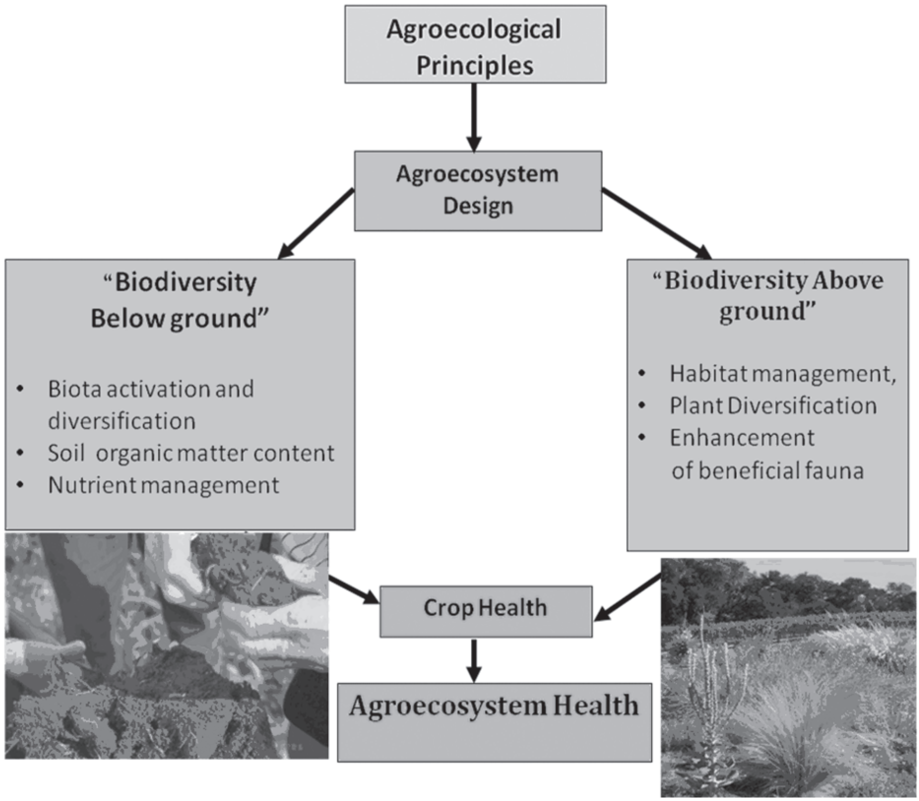
The components of functional biodiversity include pollinators, predators and parasites, herbivores, non-crop vegetation, earthworms, soil micro-fauna and micro-flora. These carry out important functions such as pollination, pest regulation and improving soil structure. Once we know the components and their functions, farmers can enhance biodiversity in a multiple-use farming system. The challenge lies in how to assemble and enhance functional biodiversity.

Agroecology has two pillars that we need to focus on: soil quality (below ground, i.e., enhance organic matter and biological activity) and plant health (above ground, i.e., enhance habitat for beneficial biota) (Figure 4). Both pillars interact and complement each other. Soil fertility can be enhanced by different practices, such as the use of organic fertilizers, cover crops, green manures, mulching, compost, intercropping and crop rotations. Pest regulation can be enhanced with crop diversity, cultural practices, microbial insecticides and habitat modification (Figure 5).

The first step in the conversion of farms to agroecology is diversification, whereby the monoculture is broken. As biodiversity increases, there will be more beneficial interactions and high resource-use efficiency. An increasing body of literature documents the effects that plant diversity has on the regulation of insect herbivore populations by favouring the abundance and efficacy of associated natural enemies. Research has shown that mixing certain plant species usually leads to density reductions of specialized herbivores.

Agroecology is preventive and not curative in nature, i.e., creating systems that inhibit pest invasion. Weeds can provide flowers with pollen and nectar that beneficial insects need. But to avoid weed infestations, farmers need to cut the weeds before they seed. Another alternative is to plant flowers in the system to attract and feed natural enemies. This

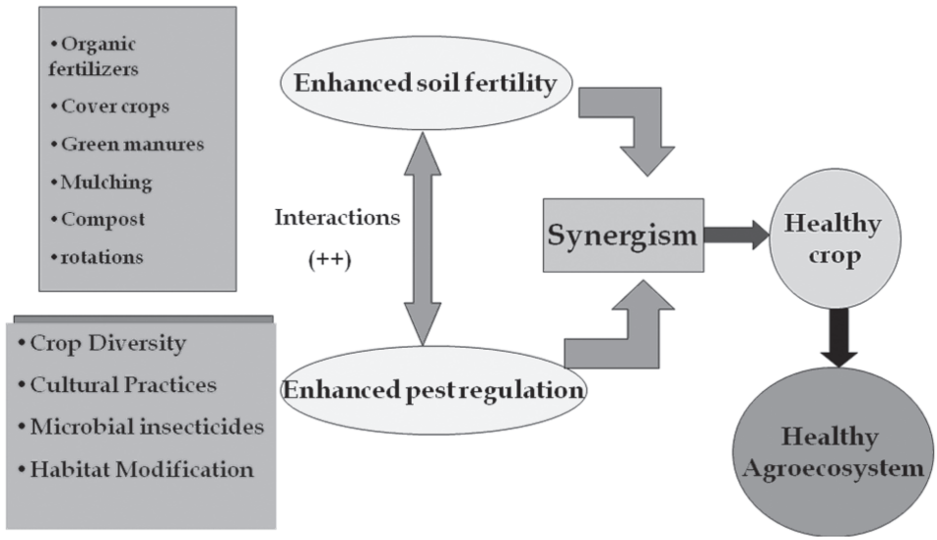
Figure 4. The two fundamental pillars of the agroecological conversion process



creates an ecological infrastructure for natural enemies of pests. The plants should be flowering all the time throughout the growing season and must be present before the crops are planted, so that an army of beneficial insects build up before insect pests reach too high densities. Natural enemies work best at lower densities of pests, so we need to build and maintain their levels as a preventive approach.

Planting strips or corridors of flowers in the middle of crops or as borders breaks the monoculture and provides pollen and nectar for natural enemies that can move to the adjacent crop and control pests. Several researchers have introduced flowering plants in strips within crops as a way to enhance the availability of pollen and nectar, necessary for optimal reproduction, fecundity and longevity of many natural enemies of pests. Commonly used

Figure 5. Synergies between pest and soil fertility management practices that lead to optimal soil quality and plant health



flowers include *Phacelia,* buckwheat and *Alyssum* strips in various crops, leading to enhanced abundance of aphidophagous predators especially syrphid flies and ladybugs that consequently reduce aphid populations. Many predators and parasitoids only move 50 m from the forest edge or the corridor, which means that corridors should be established every 100 m. The distance between each flowering strip or corridor depends on the insects you wish to attract, e.g., if they are flying or creeping insects. There needs to be consideration of the size and shape of the flowers and the exposure of the pollen. Different insects are attracted to different kinds of flowers. Flowers that are good for natural enemies are usually small, open, but not too tubular so that the nectar is easily accessible to all kinds of insects, otherwise they will not be effective in providing food to beneficial insects.

Why are pests attracted to monocultures? Many pests use visual and/or olfactory clues to locate crops. It is easier for pests to find the plant (by smell and sight) if there is a monoculture. In Costa Rica, where it was not possible to grow tomatoes due to high virus-transmitting whitefly populations, one innovative farmer grew tomatoes successfully along with cilantro, as the whitefly could not find the tomato. When corn is grown with beans and squash, the pests are confused, so it is more difficult for them to colonize the crop. The squash is also a good border trap crop, especially for cucumber beetles. Monocultures do not provide pollen and nectar for beneficial insects (predators of pests), unlike a polyculture. So in a polyculture natural enemies find many resources and build up in numbers, regulating pests. In Africa, researchers developed a push-pull system associating plants with maize, some of which attract the parasitoids of the pest while others attract the pest away from maize (acting as a trap crop). Napier and sudan grasses are used as border trap crops. Molasses grass and silverleaf (*Desmodium*) are planted as intercrops to repel the maize stem borer (Figure 6). *Desmodium* also suppresses the growth of the striga weed, fixes nitrogen, and is excellent forage for increasing milk production in cows. The system produces a 15-20 per cent increase in maize yield and a return of $2.30 for every dollar invested.

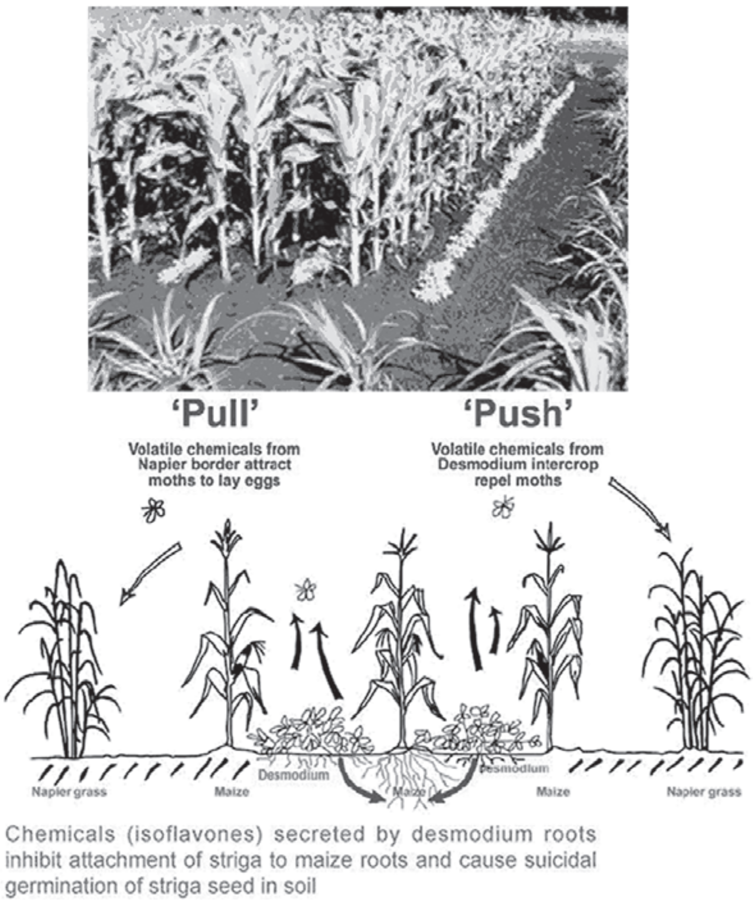
Even certain weeds play an ecological role. They should not be so abundant as to compete with the crop. We need to discover the critical period of competition of weeds, for example, only allowing weeds after the crop's cycle so that the crop is established. There are weeds that trap insects and weeds with repellent action, while flowering weeds serve as a source of alternative food for beneficial insects (pollen, nectar, neutral insects).

For example, in Mexico, a weed (lupin) is grown with maize because it is more attractive to pests than the maize. When the weeds are full of the pests, the farmers cut and burn them. Another example is wild brassica, which insects prefer to cabbage because the former has six times more essential oils than cabbage and is more attractive to insects such as cabbage worms and flea beetles. In Colombia, grass weeds grown around beans act as a repellent to pests because they emit a particular odour that leafhopper pests do not like. Certain weeds can also provide cues (akin to 'cries for help' when attacked by pests) to attract beneficial insects.

Cuba has shown that polycultures can be successful on a large scale and researchers there have identified combinations of crops that regulate specific pests; for example, sweet potato and maize grown together control sweet potato weevil. The pollen of maize attracts predators and so maize can be used to enhance the population of predators as well as act as a physical barrier to avoid dispersion of pests (such as thrips) to other plots. Maize grown with vetch controls nematodes. Another widely used combination is maize and beans. Different combinations of plants can be used to control different pests, e.g., using cassava with beans to control cassava pests and growing cabbage with sesame to control the whitefly.

Different kinds of cover crops serve different functions, for example, to enhance soil structure, improve soil fertility and manage pests. Legumes are used mainly to increase soil fertility while a mix of legumes and grass improves soil structure. Cover crops serve as habitats for natural enemies to control pests. Ladybugs, ground beetles, spiders and wasps are very important predators that are to be encouraged. Cover crops must be planted early

Figure 6. The push-pull system to control the stem borer in Africa combines plants that act as trap crops of the pest and others that attract parasitic wasps of the pest



when the population of the pest is low so there is time to build up the population of natural enemies. The cover crops must be mowed regularly to force the predators to move to the crops to find prey, otherwise they may just stay in the cover crop area. The timing for forcing the movement is critical and must coincide with the most vulnerable stage of the pest. This can be determined by closely monitoring populations.

Animals can also be used to control pests. For example, fish in rice fields can consume weeds and push the rice plants in a way that shakes off the pests. The fish then feed on the leafhoppers that fall off. Ducks can also be used to control the larvae of many insect pests.

Landscape heterogeneity is important too. If there is diversity in the surrounding landscape, this can be used and connected with the farm, allowing natural enemies to disperse into the crop fields. Sometimes, instead of corridors, 'islands' can be made. These islands composed of flowering plants serve as habitats of natural enemies where they concentrate. Placing perches or nest boxes for birds is another strategy, as birds are efficient in controlling the population of certain types of insects.

Chapter Five

AGROECOLOGICAL BASIS FOR THE CONVERSION TO ORGANIC MANAGEMENT

HOW does one convert from a high-input conventional to a sustainable low-external-input agricultural system? Many people conceptualize this conversion as a transitional process with three marked phases:

(1) **Increased efficiency of input use** as emphasized by traditional integrated pest management. In this stage, for example, with Integrated Pest Management (IPM), fields are monitored to see if there is a pest population, and action (application of pesticides or repellents) is only taken when a certain threshold of damage, injury or pathogenicity is reached. It is a good step as it reduces the use of pesticides and encourages more selective usage, but the agroecology goal has not been reached yet.

(2) **Input substitution** or substitution of agrochemical inputs with environmentally benign inputs as practised by many organic farmers. This second stage is where farmers use external inputs such as commercial compost or botanical pesticides, which occurs in the majority of organic farms. However, such farms may still be monocultures, thus the ecological infrastructure of the system has not changed. Although chemical pesticides are not used, sometimes farmers use a product that contradicts another, e.g., applying sulphur to kill a plant pathogen, which also kills many beneficial insects. Input substitution is not the same as agroecology. The former focuses on the symptoms, overcoming of limiting factors, external inputs, maximization of yields, monocultures and usually one product, while agroecology deals with root causes, optimizing processes, interactions and synergy, stabilization of yields, diversification and multiple functions and products. Increasingly many organic farmers are getting closer to the agroecological approach, but more could still be done to reduce external inputs.

(3) **System redesign**: diversification with an optimal crop/animal assemblage, which encourages synergism so that the agroecosystem may sponsor its own soil fertility, natural pest regulation, and crop productivity. To redesign farms there are two ways to break monocultures: by introducing temporal and spatial diversity. Diversity can be built over time by using crop rotation, including a “charging phase” – where the system enhances organic matter (e.g., through legumes) – alternating with an “extracting phase” with more demanding crops (e.g., cereals). A good rotation has to have an equilibrium between the two phases.

Many of the practices currently being promoted as components of IPM or organic farming fall in categories 1 and 2. Both of these stages offer clear benefits in terms of lower environmental impacts as they decrease agrochemical input use and can often provide economic advantages compared to conventional systems. Incremental changes are likely to be more acceptable to farmers than drastic modifications that may be viewed as highly risky or that complicate management. But does the adoption of practices that increase the efficiency of input use or that substitute biologically based inputs for agrochemicals, but leave the monoculture structure intact, really have the potential to lead to the productive redesign of agricultural systems?

In general, the fine-tuning of input use through IPM does little to move farmers toward an alternative to high-input systems. In most cases IPM translates to "intelligent pesticide management" as it results in selective use of pesticides according to a predetermined economic threshold, which pests often 'surpass' in monoculture situations. On the other hand, input substitution follows the same paradigm of conventional farming: overcoming the limiting factor, but this time with biological or organic inputs. Many of these "alternative inputs" have become commodified, therefore farmers continue to be dependent on input suppliers, many of a corporate nature. Clearly, as it stands today, "input substitution" has lost much of its ecological potential.

System redesign, in contrast, arises from the transformation of agroecosystem function and structure by promoting management guided to ensure fundamental agroecosystem processes. Promotion of biodiversity within agricultural systems is the cornerstone strategy of system redesign, as research has demonstrated that higher diversity (genetic, taxonomic, structural, resource) within the cropping system leads to higher diversity in associated biota, usually leading to more effective pest control and tighter nutrient cycling. As more information about specific relationships between biodiversity, ecosystem processes, and productivity in a variety of agricultural systems is accumulated, design guidelines can be developed further and used to improve agroecosystem sustainability and resource conservation.

5.1 Crop rotations

Crop rotations are key strategies to start the conversion process. A farm can be divided into four to six large fields such that after a period of time a succession of crops circulates in every field. The rules for good rotation include: avoid planting the same crop family in the same field; alternate cover crops with cash crops; alternate deep-rooted crops with shallow, fine-rooted crops; precede heavy feeders (like corn and rice) with nitrogen-fixing crops; and avoid following a root crop with another root crop. There is a rule in crop rotation that determines the optimal time before which one can grow the same plant family in a plot of soil to avoid build-up of pathogens in the soil. This also helps to optimize the diversification of the system as no one plant family dominates the rotation (Figure 7).

Rotations essentially break the life cycles of diseases and certain combinations of crops eliminate or reduce pests/diseases. Rotations decrease diseases by incorporating plants that are toxic to pathogens – this is called bio-fumigation. Plants in the Cruciferae family (brassicas) like mustard have a chemical in their tissues which, when churned under, releases secondary compounds (glucosinolates or allelochemicals) which act as bio-fumigants that kill pathogens in the soil. Other plants that have this effect include marigold and Crotalaria.

Rotations can break the cycle of pests, especially when rotated crops belong to different botanical families. Some pathogens that cause diseases survive in the soil from year to year in one form or another, usually as sclerotia, spores or hyphae. Continuously cropping the same crop builds up the population levels of any soil-borne pathogen of that crop that may be present. The populations can potentially build up to such an extent that it becomes difficult to grow that crop without yield losses. But growing a crop that is not a host plant for that pathogen will lead to the pathogen's death due to starvation.

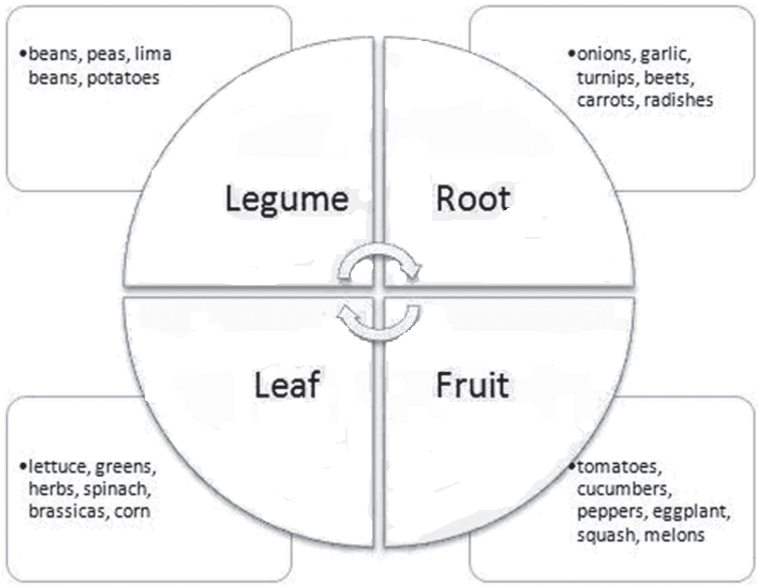
Rotations also reduce weed populations by breaking their life cycles. The biomass of weeds under crop rotation with green manure is reduced and that of the crop is increased. Green manure helps the crop but also suppresses weeds, as opposed to chemical fertilizers that stimulate the growth of large seeded weeds.

How can we avoid losing nitrogen from the soil in a rotation? One way is to grow a legume and, when it is flowering, to undersow wild mustard. Once the legume is harvested, the mustard will capture the nitrogen that would otherwise be lost from the soil because there is too much time between the legume and the next crop. The mustard acts like a bridge that retains the nitrogen in the system until the new crop (cereal) is planted.

We can incorporate the mustard into the soil before planting maize. Mustard also has allelochemical properties. In southern Brazil, the farmers usually plant three cover crops: vetch, forage radish and rye as green manure. They then roll over the crops to flatten them. The material will start decomposing and releasing allelochemicals that form a toxic layer in the top two centimetres below the soil surface. This kills most of the weeds as the weed seed bank is in the first 2-3 cm of the soil. So the weed (or any other) seeds will not germinate in this toxic layer. The farmers sow maize and beans seeds deeper into the soil, say 3 or 4 cm deep, so they will not be affected by the toxins and freely germinate. The farmers discovered this through observation and experimentation.

Some benefits of rotation only take place over a long time. After a few years generally there is no statistical difference in the yields of conventional and organic crops. However, organic farms do better in droughts since organic matter acts like a sponge, increasing the water-absorbing capacity of soils. In addition to the above benefits, rotations maintain healthy soil, allow diverse products for the market that will provide economic stability, diversify

Figure 7. An optimal crop rotation with sequences of distinct functional groups or families of plants that have various nutrient requirements and do not share pest complexes



tasks to spread labour out over the year to keep workers happy and productive, and minimize off-farm inputs and capture solar energy wherever possible.

5.2 Enhancing soil health

The most important goal of conversion is to enhance soil health. We want to have soil that has good structure and a lot of organic matter, and soil biological activity. Organic matter produces substances that allow soil particles to aggregate, with lots of micropores where water and air can permeate. Soil organic matter provides the fuel for microbes and meso- and macro-fauna. Through decomposition, the soil microbes mineralize minerals that become used by plants. Just 10 grams of soil contain millions of organisms that interact in very complex food webs.

As the microbial biomass is concentrated in the top layer of the soil, we have to protect topsoil. Large quantities of organic matter – different kinds like fresh and dry leaves (cellulosic material), branches (lignin), compost, etc. – should be applied to soils on a regular basis. Soil cover should be maintained with cover crops and mulches. Erosion can cause the loss of not only nutrients but micro-organisms too, and should be minimized with proper soil conservation measures. The loss of 1 mm of soil is equivalent to 14 tonnes per ha. To rebuild that will take 50-100 years with good practices.

The basic ecological principles behind soil biological management are:

- The supply of organic material for food. There are two types of organic material, labile and non-labile. Labile organic matter decomposes quickly and usually comes from leaves and straw. Non-labile material decomposes more slowly, such as lignins and branches from trees. A mixture of both labile and non-labile material is needed to produce good organic matter. Material that decomposes quickly provides nutrients while those that decompose slowly give structure to the soil. Farmers also need to stimulate soil organisms with good temperature, nutrients and air.
- Increased plant diversity. Many plants release substances from roots (root exudates). Each exudate stimulates a different population of bacteria. The more the exudates, the more complex the soil microbiology near the roots.
- Maintain good soil structure to stimulate microbes and improve water, air, temperature and nutrient conditions.
- Use different types of organic materials because they have different effects on soil biological, chemical and physical properties.
- Keep soil covered with living vegetation and/or crop residues by using cover crops, sod crops in rotations, and/or reduced tillage practices. This encourages water to infiltrate into the soil instead of running off the field, taking sediments (and organic matter) along.
- Reduce soil compaction to a minimum by keeping off fields when they are too wet, redistributing loads, using traffic lanes, etc.
- Use a variety of practices to reduce erosion. These include some mentioned above, such as keeping soil covered with living vegetation or crop residues (using cover crops, rotation sod crops, and reducing tillage), as well as other practices such as terracing, grassed waterways, strip cropping along the contour by alternating a row crop with a sod crop, using natural or planted buffers between fields and streams, etc.
- Use practices to supply supplemental fertility sources, when needed, that better match nutrient availability to crop uptake needs (which vary during the season). This helps to reduce both weed and insect damage.

When we add organic matter, we increase the carbon in the soil and create conditions for balanced biota. The food web in the soil becomes very complex, with bacteria, fungi, nematodes and protozoa all playing a role. Some soil organisms feed on other organisms and control their populations; for example, there are nematodes that eat fungi and vice versa. Other micro-organisms mineralize nutrients, others protect crops against pathogens and others produce plant-growth-promoting hormones (Figure 8). In the rhizosphere, there are not just plant roots, but also thousands of beneficial bacteria and fungi that surround the roots. Mycorrhizae help plants to acquire certain nutrients such as phosphorus and improve water use efficiency. If there is drought, crops with mycorrhizae survive better than crops without. Mycorrhizae also cover roots and protect them against pathogens. It is difficult to introduce mycorrhizae into a planted field. It is best to harvest litter from a nearby natural forest, which has a lot of mycorrhizae, and then incorporate this material in the compost so as to inoculate it.

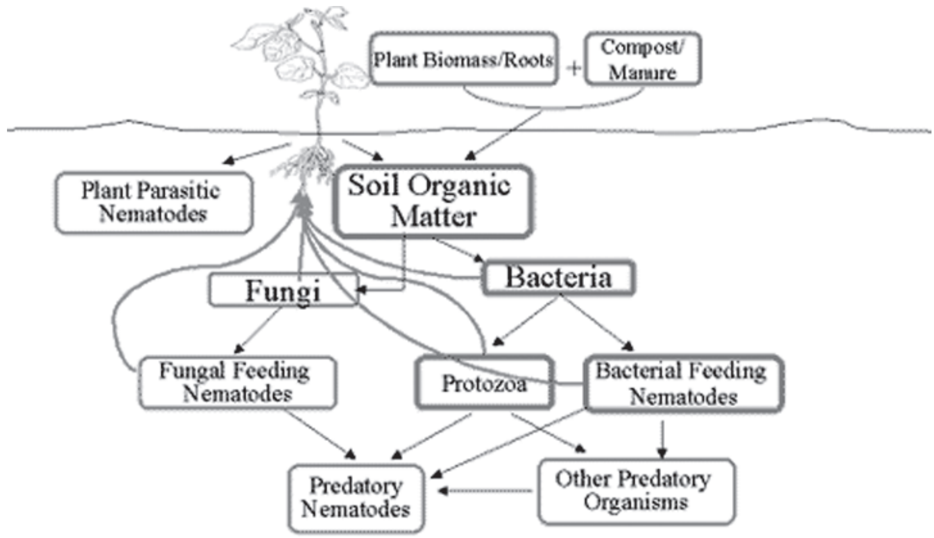
5.3 Crop diversity

Increasing plant diversity in agroecosystems provides checks and balances, nutrient availability to plants, checks on disease outbreaks, etc. Intercropping is an important strategy, given that it enhances plant diversity, with crop combinations that can complement each other. For example, intercropping can reduce disease incidence. In order for a disease to occur, there must be a susceptible plant, a favourable environment (temperature, humidity, soil conditions) and an aggressive pathogen with many races (this is called the "disease triangle"). Intercropping can alter temperature and humidity to levels that are not favourable to the pathogen. Intercropping mixes varieties of different plants of various heights, so that tall plants block the dispersal of the disease spores. A Chinese experiment found that alternate rows of short and tall rice varieties greatly reduced the incidence of disease and fungicide use, hence increasing yields. The tall rice varieties had blocked the movement and spread of fungal spores.

Intercrops can include varieties that exhibit horizontal resistance. Usually, traditional crop varieties have medium resistance to all pathogen races (horizontal resistance), but Green Revolution crop varieties tend to have vertical resistance (a high degree of resistance to a single race of a pathogen, but not to other races), making modern varieties more vulnerable.

Can this work on a large scale? Simpler diversification schemes based on two or three plant species may be more amenable to large-scale farmers and can be managed using modern equipment. One such scheme is strip intercropping, which involves the production of more than one crop in strips that are narrow enough for the crops to interact, yet wide enough to permit independent cultivation. Agronomically beneficial strip intercropping systems have usually included corn or sorghum, which readily respond to higher light intensities. Studies with corn and soybean strips 4 to 12 rows wide demonstrated increased corn yields (5 to 26 per cent higher) and decreased soybean yields (8.5 to 33 per cent lower) as strips got narrower (Figure 9). Alternating corn and alfalfa strips provided greater gross

Figure 8. A complex soil food web typical of soils rich in organic matter, with a collection of antagonists, decomposers and plant-growth-promoting micro-organisms



returns than single crops. Strips of 20 ft (approximately 6.1 m) width were the most advantageous, with substantially higher economic returns than the single crops. This advantage is critical for farmers who have debt-to-asset ratios of 40 per cent or higher ($40 of debt for every $100 of assets). Such a level has already been reached by more than 11-16 per cent of farmers in the mid-western United States who desperately need to cut costs of production by adopting diversification strategies.

Building an ecological infrastructure is the last stage of the design where one deploys biodiversity in time and space optimally. An agroecological farm can supply all the dietary needs of farmers and their families, with surplus, via diverse foods and nutrients. Once the system is working, it takes care of itself and there is no more need for a lot of external inputs or much labour.

Large-scale agroecological conversion on cooperative farms has been achieved by introducing contour farming on slopes, restoring corridors of biodiversity, green manure application to recover soil fertility, planting trees, strip intercropping, rotation, relay green manuring providing multi-strata habitats such as hedges with multiple species of trees and shrubs which also provide flowers, fruit, fuel and protect against wind, and integration of livestock, which are equally important agents of recycling and pest control. Animals integrated into the farm eat all the crop residues and provide manure for fertilization. It is important to select the right animals, for example, local animals that do not demand too much energy and food. In Brazil, family farmers release chickens into the field once the crops have grown to a certain height to control pests, produce manure and control weeds. In Colombia, farmers use guinea pigs to feed on grass. The urine and manure from these animals are good fertilizers and can be used to make vermicompost, and their manure can also be fed to fish.

5.4 Indicators of sustainability

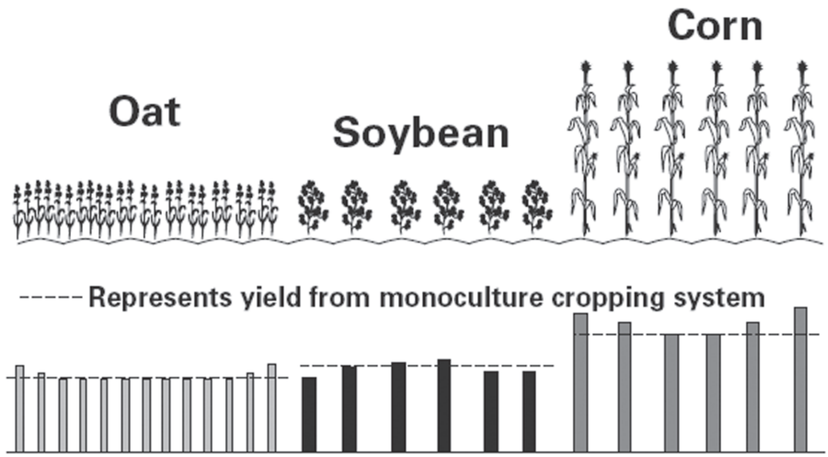
Conventional agriculture is not sustainable. How can we evaluate an agricultural system to see if it is sustainable?

Firstly, we need to see if the system is being managed according to agroecological principles. Is it enhancing spatial and temporal genetic and species diversity at farm and landscape levels; is it promoting crop and animal integration (nutrient cycling); is it enhancing biologically active soils and promoting high biomass recycling rates; and is it optimizing the use of space (agroecological design)? Many tools have been developed to assess the sustainability of farming systems. One methodology offers a set of indicators (see Box 5) consisting of observations or measurements that are done at the farm and landscape levels to assess agroecological features of the farms and the performance of the farming systems and determine if changes in species biodiversity, soil quality, plant health, crop productivity, etc. are positively evolving. If this is not the case, the methodology offers the opportunity to prioritize the agroecological interventions necessary to correct observed soil, crop or system deficiencies.

Soil quality indicators include: soil structure, signs of erosion, compaction, percentage of soil cover, root development, soil micro-organisms, colour and odour of the organic matter, presence of invertebrates, and microbiological activity. Crop health indicators include disease and pest incidence, functional diversity (abundance and diversity of natural enemies) and so on. Since all the measurements made are based on the same indicators, the results are comparable and it is possible to follow the evolution towards resilience of the same agroecosystem along a timeline, or make comparisons between farms in various transitional stages.

Each indicator is valued separately and assigned a value between 1 and 10, according to the attributes observed in the soil or crop (1 being the least desirable value, 5 a moderate or threshold value and 10 the most preferred value). Once the indicators are applied, each farmer can visualize the conditions of his or her farm, noticing which of the landscape, soil or plant attributes are sufficient or deficient compared to a pre-established threshold.

Figure 9. Yield comparison of a three-crop strip intercropping with monoculture cropping (the broken line is the yield of each crop under monoculture) as affected by row position. The positive edge effect in corn occurs mainly in the rows at the crop strip border with soybean. This positive effect may extend to the second outside rows; however, the yield in the centre of strips wider than four rows is equivalent to sole-cropped corn.



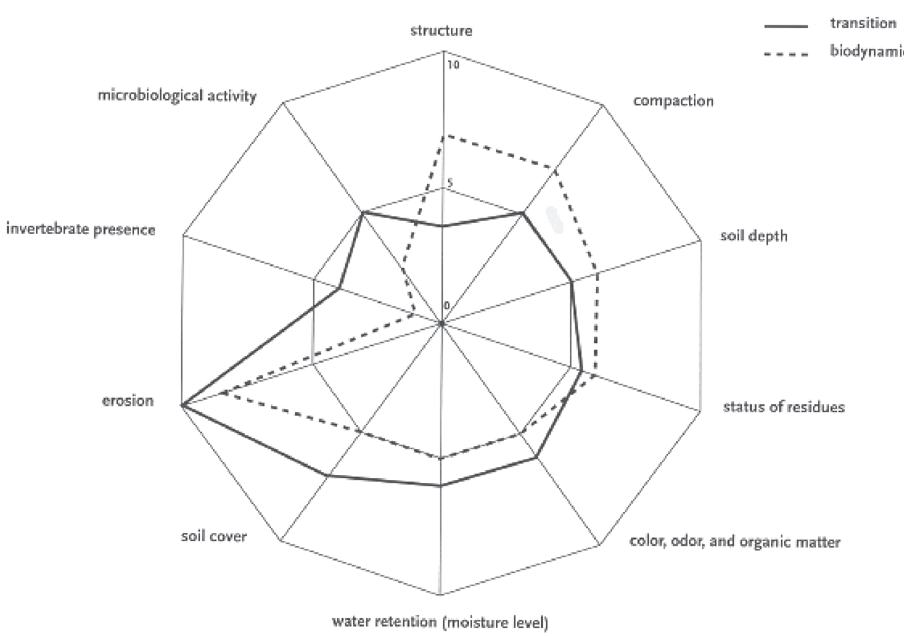
Box 5: Indicators used to assess if farms are utilizing agroecological principles in their design and management

- Landscape diversity (amount and type of vegetation surrounding farm)
- On-farm crop and animal diversity (number of species)
- Genetic diversity (number of local crop varieties and/or animal races)
- Soil quality (organic matter content, structure, soil cover, infiltration, etc.)
- Signs of degradation or resource losses (soil erosion, deforestation, habitat fragmentation, state of water courses, efficiency in use of water, nutrients, etc.)
- Plant health (presence of pests, diseases and weeds, crop damage)
- Dependence on external inputs (percentage of inputs originating outside farm)
- Levels of food self-sufficiency (percentage of food originating on farm)
- Interactions and bioresource flows between farm components (recycling of crop residues and manure, effective use of biomass, complementarities between plants, level of natural pest control, etc.)
- Resilience to external disturbances (capacity to resist and recover from pests, droughts, storms, etc.)

The indicators are more easily observed by using an amoeba-type graph as it allows one to visualize the general status of soil quality and crop health, considering that the closer the amoeba approaches the full diameter length of the circle, the more sustainable the system (a 10 value). Farms with an overall value lower than 5 in soil quality and/or crop health are considered below the sustainability threshold, and rectifying measures should be taken to improve the low indicators on these farms (Figure 10).

The amoeba graph shows which indicators are weak (below 5), allowing farmers to prioritize the agroecological interventions necessary to correct soil, crop or system deficiencies. At times it may be possible to correct a set of deficiencies just by addressing one specific attribute. For instance, increasing species diversity or soil organic matter will in turn affect other system attributes. By adding organic matter, one is increasing the soil's water-carrying capacity, augmenting soil biological activity, and improving soil structure.

Figure 10. Amoeba diagram representing the soil quality status of two vineyard systems (transitioning to organic, and biodynamic) in northern California. The biodynamic farm exhibits better soil quality values for structure, compaction, status of residues, and soil depth, while the transition farm exhibits higher values for biological activity, soil cover, water retention, and organic matter, probably reflecting the positive effects of maintaining the dry cover as mulch.



Chapter Six

AGROECOLOGY AND FOOD SOVEREIGNTY

THERE are about 1.5 billion peasants in 380 million small farms worldwide. Fifty to 75 per cent of the world's food is produced by small farmers, even though they only control 25-30 per cent of the land, and use 30 per cent of the water and 20 per cent of the fossil fuels used in agriculture. Globally, more than 90 per cent of the world's farms are small, less than 2 ha. These farms have contributed to agricultural biodiversity by breeding 7,616 animal races and 1.9 million crop varieties since 1960, which are freely available to humankind (in contrast to the Green Revolution which has produced only 8,000 new crop varieties since 1970). Small farms are more productive than large farms, if the total output is considered rather than yields from a single crop. They also have a tendency to use locally available resources in an efficient manner and rely on indigenous knowledge.

Small farmers play important roles as custodians of agricultural biodiversity, repositories of indigenous knowledge, producers of food, innovators and experimenters. Much of the agricultural biodiversity has been maintained through cultural traditions, which include community seed banks and community harvesting encouraging exchange of many varieties.

Many small farmers use agroecological techniques such as intercropping and complex systems. These farms are not new and have existed for centuries. For example, the *chinampas* were developed by the Aztecs 5,000 years ago, and consisted of mixed agriculture and aquaculture. Small, rectangular artificial islands were made in shallow lake beds. The mud was used as fertilizer, and floating weeds were composted and contributed to the recycling of organic material. The system was very productive and supported fish, ducks, chicken, maize, beans, vegetables and fruit trees. One hectare of land could produce enough food for 15-20 persons per year. The *chinampas* fed more than 10 million people of the Aztec empire.

Another example is in the Andes, where farmers still manage the terraces that were created 5,000 years ago. There are about 120,000 hectares of terraces planted to sweet potato, potato, and Andean crops rich in protein such as amaranth and quinoa. There are efforts going on to recover terraces that have been abandoned, by using lupin, which is a legume, as a green manure.

The ancient *waru waru* system in the Andes combines raised beds with irrigation channels. It allows the production of potatoes and grains at 4,000 m above sea level, despite the frost. Water absorbs heat in the day and the heat is released at night, changing the microclimate. It is a perfect adaptation strategy that was developed thousands of years ago. The system was destroyed by colonialism, but there are hundreds of farmers who are now reconstructing the system. So far, some 4,720 hectares have been recovered.

Agroecological methods produce more food on less land, using less energy and less water while enhancing the natural resource base, providing ecological services and lowering outputs of greenhouse gases. Agroecology is not one more tool in the toolbox to fix the problems of conventional agriculture. It is an alternative system; a break away from conventional agriculture. Food sovereignty means bypassing the industrial system of agriculture to make food systems more localized and less globalized. Agroecology provides the production strategies and methodologies, and needs strong social movements to organize and spread the technologies and pressure governments to provide access to markets, credit and agroecological extension and research. A central issue is land reform so that peasants can have access to land, water and seeds.

Food sovereignty is about the right to healthy harvests, the right to food that is culturally appropriate, and the right of each country or peoples to define their own food policies without intervention from outside. Food sovereignty is also the right to produce with fair prices for consumers and producers. There is an emphasis on access to national and local markets for small-scale producers; produce is exported only after requirements at local and national levels are met.

Governments need to put in place appropriate policies: for example, to protect small farmers against free trade, provide them with credit, eliminate monopolies, scale up agroecology projects, protect public goods research, and so on. One fundamental aspect of food sovereignty lies in seeds, which are peoples' patrimony at the service of humankind. Food sovereignty is also tied to energy sovereignty and technological sovereignty, which in the case of agroecology means that there is no need to use inputs, promoting the use of farm-saved seeds. Features of appropriate technologies for poor farmers are that they are: based on indigenous knowledge and rationale; economically viable, accessible, and use local resources; environmentally sound; socially just; risk-averse; and enhance total farm productivity and stability. Cuba provides an amazing example of what can be achieved with agroecological agriculture (see Box 6).

Box 6: Cuba – A model of agroecological agriculture

Historically, Cuban agriculture was one of monocultures, export orientation, and natural resource exploitation. After the revolution, there were changes in socio-economic terms, but not in natural resource exploitation and industrial agriculture. Prior to the collapse of the Soviet Union in 1990, Cuba traded sugar in exchange for fertilizers, pesticides and petroleum. Agriculture then was very industrial, with heavy use of chemical pesticides and fertilizers.

The motivation for its agricultural redesign was its economic collapse following the collapse of the Socialist bloc. Without resources from abroad, the inefficiency and fragility of its industrial agricultural system became apparent; it could not function. Cuba faced low food self-sufficiency, high external dependence and deeply rooted socio-economic problems in the countryside. Cuba is unique in that the revolution invested in education, resulting in a country that makes up two per cent of the Latin American population having 11 per cent of the scientists. Cuba thus had human capital and with no inputs forthcoming, they were forced to go organic and realize the importance of peasant agriculture.

From 1990-2014, three fundamental trends emerged in Cuba:

- A change from monoculture to diversification by increasing diversity and heterogeneity.
- A move from centralization to decentralization. This involved changes in land tenancy structure, a decline in state-owned lands, and reductions in farm size.
- A move from dependence on food imports to food self-sufficiency, prioritizing local food production over exports.

The process of conversion to agroecology took place at four levels:

Level 1 – increased efficiency of conventional practices by, for example, using legumes, reducing energy inputs, and improving technology efficiency;

Level 2 – input substitution, e.g., biological pest control and better use of renewables;

Level 3 – system redesign, based on ecological processes;

Level 4 – agroecological connection; developing a culture of sustainability that considers all interactions between all components of the food system.

Urban agriculture has also developed rapidly in Cuba, as the petroleum shortage resulted in production moving from rural to urban areas. Urban agriculture became the model for the transformation of rural agriculture. Urban and peri-urban agriculture is supported by state policy. Sixty per cent of the vegetables consumed in the cities now come from a variety of urban and peri-urban farms. On average, these farms produce 18.444 kg/m^2/year. Cities have also started recycling programmes to make compost for use in urban agriculture. There is also traditional poultry production, which requires selection of suitable races of chicken adapted for the urban environment.

The contribution of small farmers to agriculture increased after the collapse of the Soviet Union. The farmer-to-farmer network "*campesino y campesino*" has enabled many farmers to switch to organic and natural farming. Today, there are some 20,000 families practising agroecology from 216 some years ago. These families use agroecological strategies such as polycultures, animal integration, crop rotation, green manure and organic amendments. Their most sophisticated technology is animal traction, which allows them to get into the fields after the rains. There is also a lot of innovation with organic fertilizers, for example, compost with forest litter. Many small farmers work on the hillsides and have also used local technologies for water harvesting to ensure that their plots are well irrigated.

The small farms are extremely productive. Small farmers with 25 per cent of the land are able to produce more than 65 per cent of the domestic food supply. For example, there is one farm that has a land equivalent ratio of 1.76, that is, it is 76 per cent more efficient than its neighbours with monocultures. That farm can produce enough food to feed 21 people carbohydrates and enough protein to feed 12 people from one hectare of land. The actual size of the farm is 40 hectares, so it can feed about 800 people. It is also energy-efficient, putting in 1 kcal and getting back 11 kcal. Another farm is diverse with a dynamic system of rotation, and includes fruit trees, pastures, crops, and multi-purpose hedgerows. It produces multiple products such as food, forage and charcoal, and can feed 34 people with protein per hectare, and is energy-efficient. Many of the farms also conserve and sustainably use curative diversity, incorporating medicinal plants.

Chapter Seven

AGROECOLOGY AND THE DESIGN OF RESILIENT FARMING SYSTEMS FOR A PLANET IN CRISIS

NATURAL disasters are often costlier than technological and economic disasters. With climate change, these are likely to become more frequent. At the same time, the phenomenon of climate refugees is already happening. Can modern agroecosytems confront climatic extremes? The effects of climate change are linked to industrial agriculture, and these conventional large-scale monoculture systems due to their homogeneity and associated vulnerability have suffered a lot due to climate change impacts, such as drought.

There is also the issue of climate justice – who causes climate change and who suffers the most? In the agriculture sector, it is conventional agriculture that is producing more emissions than traditional agriculture. Those who farm traditionally do not produce much emissions and did not have anything to do with climate change, but are suffering the most. There is therefore an ecological debt owed by those who promote industrial agriculture.

The risk an agroecosystem is exposed to can be measured with this equation:

$$\text{Risk} = \frac{\text{Threat + vulnerability}}{\text{Response capacity}}$$

The agroecological definition of resiliency is the propensity of a system to maintain its organizational structure and production after a perturbation. Shocks can consist of frequent stressful events that can be cumulative or unpredictable. Resiliency exhibits two properties: the capacity to resist shocks and the capacity to recover from shocks. Resilient farms are therefore at lower risk from climate change.

There are also different types of resiliency:

- Ecological resiliency – which pertains to the design of a system; and
- Social resiliency – which focuses on the management of the landscape by social networks.

The components of agroecosystem resilience are: diversification at the genetic, species and landscape levels (through agroforestry, polycultures, and animal integration); complexity of landscape matrices; and soil and water management.

In the Andean region in Peru, farmers have diversified their varieties according to the altitude, which is at least 4,000 m above sea level. They have divided the slopes into different belts and planted them accordingly. If a particular crop is destroyed because of frost, risk is minimized as the farmers have planted different crops at different altitudes. There is also social resiliency as the slopes are managed communally.

Another way of building resiliency is through polycultures; for example, in the Mexican highlands, farmers do not only rely on maize, which is susceptible to frost, but also plant other, complementary food crops such as fava beans, which can better withstand frost. Another important strategy in adapting to climate change is the conservation of genetic landraces resistant to drought. Centres of origin and genetic diversity harbour thousands of varieties, some of which would perform well in low water situations or at different altitudes. In Mexico for example, farmers plant a specific maize landrace which can perform well without much water. How it is grown also contributes to the crop's drought resistance; the maize is planted about 20 cm deep, where compost is added, protecting the seedling from desiccation.

Crop diversification can enhance the resiliency of agroecosystems and protect production capacity in various ways including protection of crops against extreme weather effects and fluctuations in water and temperature. For example, during Hurricane Mitch, which devastated parts of Central America in 1998, diverse farms using soil conservation practices (such as mulch, living or dead barriers, terraces) were better able to resist the impact of the hurricane than farms managed under monoculture. The occurrences of mudslides in conventional farms were higher than in agroecological farms. Although the latter did also suffer, they recuperated faster, demonstrating resiliency.

Similarly, when Cuba faced Hurricane Ike in 2008, areas under industrial monoculture suffered more damage and exhibited less recovery than diversified farms. Losses were 90-100 per cent for the former as compared to 50 per cent for the latter. The diversified farms were protected by hedgerows; although they still suffered damage, they were able to recover faster.

Furthermore, complex systems such as agroforestry systems provide more ecosystem services. In Colombia, for example, fruit trees are grown together with coffee and other plants. If coffee is grown without shade, it is more susceptible to pests and climate change. There is more evapotranspiration and the coffee without shade cannot survive droughts. If it is grown in shade, there will be less evapotranspiration, so that when there is a drought, the plant can survive.

Silvopastoral systems, where trees provide better microclimatic conditions and where there are also legumes that animals can feed on, are less vulnerable to drought. Silvopastoral systems are important for livestock. The more the tree and shrub biomass, the better the animals' body conditions and the higher the carrying capacity and production of the system. The three strata in a silvopastoral system are grasses, shrubs and small trees, and large trees. Such complex systems create a special microclimate where the animals can still browse grasses and shrubs even under severe dry conditions.

One factor that influences resiliency is the landscape matrix within which farms are inserted. For example, forests surrounding farms play a key role in controlling the effects of climate change, such that those farms can better withstand excessive rain, drought and other climate phenomena. In south China, most rice farmers suffered with the 2011 droughts but those living in the Yuanyang terraced region were spared since they were surrounded by forests, which played an important role in maintaining the local water cycle.

Organic matter can enhance soil structure and increase the soil's water-holding capacity. Organic crops out-yield conventional crops during drought because of the increased organic matter and higher soil moisture content. Organic matter also creates a suitable environment for plant roots. The role of fungal mycorrhizae is important; it increases the absorption capacity of roots, increases mobilization and transfer of nutrients, increases the plant's tolerance of root pathogens, and increases the production of plant growth hormones.

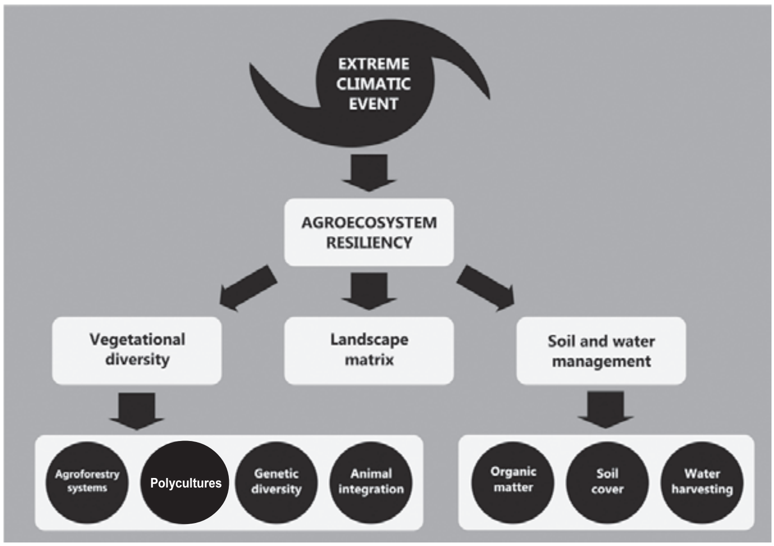
Soil cover is also important to decrease evapotranspiration. Cover crops increase organic matter in the soil and improve water storage. In Central America, farmers plant vetch as cover crops, to control erosion on slopes and to also fix nitrogen. Mulching can also reduce evaporation, conserving water for crops under stress.

Adaptation for farmers is the priority, but there could be mitigation benefits as well. The common features of successful adaptation for farms based on agroecological principles are:

- The landscape matrix influences the resiliency of farm fields as it influences the local water cycle. When biodiversity is reduced, ecosystem services such as water-holding capacity are affected.
- Organic matter and good soil structure are important for water-holding capacity, good infiltration, etc.
- Water harvesting at household, farm, and landscape levels is essential.
- Diversification is critical; genetic diversity and associated knowledge, conservation of traditional varieties, etc.

In summary, the literature suggests that agroecosystems will be more resilient when inserted in a complex landscape matrix, featuring genetically heterogeneous and diversified cropping systems managed with organic-matter-rich soils and water conservation techniques (Figure 11). Such systems also have to be managed by well-organized social networks (see Box 7).

Figure 11. Landscape, on-farm diversity, and soil and water features that enhance ecological resilience to extreme climatic events



Box 7: Socio-ecological characteristics of resilient farming systems and communities

- High levels of biodiversity and species redundancy
- High connectivity and complementarity between farm components
- High spatial and temporal heterogeneity at the farm and landscape levels
- High levels of autonomy and independence from exogenous controls
- Socially self-organized conforming configurations based on needs and aspirations
- Reflective people that anticipate and plan for change
- High levels of cooperation and exchange
- Community honours legacy and uses traditional knowledge and practices as well as local germplasm
- Human capital developed and capable of mobilizing resources through social networks

It is also very important to enhance farmers' capacity for response. How do a farmer and an agroecosystem respond to climate change? For example, if there is a drought and the farmer plants many varieties, some crops will die while others survive, so there is good capacity of response. In building reactive capacity, we need to work with farmers' knowledge, their management skills, access to resources and diversity of enterprises. On its own, agroecology is not enough to confront climate change. Farmers need to organize and there is a need to create bridges among farmers, consumers and researchers. Farmer-to-farmer networks to share knowledge and expertise are also important. 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. A community with a high level of response capacity will feature highly cohesive social networks capable of taking collective action to mobilize local skills and agroecological knowledge to enhance the overall resilience of affected farms.

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http://www.agroeco.org

Industrial agriculture is not delivering on its promise to feed the world. As its limitations and ruinous health and environmental impacts become more and more evident, the need to rethink how we farm is thrown into ever sharper relief.

Agrocecology – the application of the science of ecology to agricultural systems – is increasingly recognized as the way forward for agriculture. It is an alternative to the destructive practices and unhealthy food produced by industrial agriculture. Drawing from the workings of natural ecosystems, agroecological principles and practices provide a solid foundation for improving plant health, soil quality and crop productivity. Further, agroecology is more than a science; it is also a practice and a movement. Conceived in this manner, the knowledge of farmers takes centrestage, as does the sharing of their experiences and the spread thereof.

This booklet distills the main learning points from two training courses on agroecology organized by the Third World Network in Indonesia in 2013 and in Zambia in 2015. It is intended to serve as a resource document outlining the fundamentals of agroecology and how it can inform the design and management of truly sustainable agricultural systems.

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