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Agricultural challenges today and in the future: the beneficial role of agroecology

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Agricultural challenges today and in the future: the beneficial role of agroecology

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ABSTRACT

Interest in agroecology is growing as evidence mounts that conventional agricultural methods are unsustainable, degrading the resource base (e.g. soil, water, crop diversity, biodiversity etc.) on which they depend. Alternative ways to produce foods that build soil fertility, protect ecosystems, conserve biodiversity and reduce energy inputs, provide the possibility of long-term productivity and ecological sustainability. The International Assessment of Agricultural Science and Technology for Development (IAASTD) have supported agroecology as a key set of solutions for world agriculture, which synergistically tackle development, sustainability and conservation goals. This study presents indicators to measure the sustainability of an agricultural practice which, placed in a hierarchical pyramid, demonstrates their importance and interconnected relationships. A comparative evaluation of agroecological and conventional systems is shown to assess the effects of management practices on the indicators. Agroecological approaches differ from conventional ones as they aim to sustain the soil and ecosystems by reducing synthetic inputs and creating alternative natural processes to maintain soil fertility and manage pests. Soil fertility is the essential indicator of sustainable agriculture, it was shown to improve in agroecological systems, indicated through increased soil microbial biomass (60% higher than in conventional agriculture) and earthworm abundance (up to 88% higher than in conventional agriculture). The loss of biodiversity due to current intensive farming practices is an indicator of unsustainability. In the agroecological systems biodiversity was shown to be comparatively higher. The diversity of bird and beetle species were recorded to be 50% and 38% more abundant respectively, and bat activity was shown to be 60% higher. These are bio-indicators of sustainable agriculture. The reduced chemical inputs led to an average of 50% less energy used on the agroecological systems. The resulting effects on yields showed great variation. One long term trial showed a 20% yield reduction in the agroecological system. Yet in times of drought, when advanced cropping systems were implemented, in developing countries yields were shown to be comparable, often significantly higher. This study provides solid evidence that the world’s future food security lies in the hands of sustainable agricultural practices. Agroecology demonstrates techniques that can be used towards reaching this vital goal.

Keywords: Agroecology; Sustainable Agriculture; Sustainability Indicators; Soil fertility; Biodiversity; Energy efficiency.

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LIST OF ABBREVIATIONS

AEI - Agro-Ecological Indicators

ARS - Agricultural Research Service

DOK - bio(D)ynamic (O)rganic (K)conventional

EMA - Environmental Management for Agriculture

EP - Ecopoints

FAO - Food and Agriculture Organization

FST - Farm System Trial

GHG - Green House Gases

IAASTD - International Assessment of Agricultural Knowledge, Science and Technology for Development

IFS - Indicators of Farm Sustainability

IPCC - Intergovernmental Panel on Climate Change

LCA - Life Cycle Assessment;

MEA - Millennium Ecosystem Assessment

SADP - Sustainable Agriculture

UN - United Nations

UNCED - United Nations Conference on Environment and Development

UNEP - United Nations Environment Programme

US - United States of America

USDA - United States Department of Agriculture

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CHAPTER 1

1.1 Aim and Objectives

The main purpose of this research is to investigate the potential contribution of agroecological farming practices to the future of sustainable agriculture. ~~assess whether alternative sustainable agricultural practices can deliver solutions to the challenges facing agriculture today and in the future. The rationale is to produce a document that can demonstrate how alternative techniques to produce food can contribute to sustainability, conservation and development goals~~. Data will be gathered from long term field studies to produce a document that shows a clear comparison of divergent agricultural practices with regards to sustainability goals. With a firm evidence-base,~~d~~ ~~solutions~~ sustainable agricultural~~e~~ practices ~~could help~~could help to mitigate climate change, to protect biodiversity and ecosystems and to create food security by providing the possibility of long-term productivity and ecological sustainability.

1.1.1 Aim:

- An investigation into the potential contribution of agroecology to benefit the future of sustainable agriculture.

1.1.2 Objectives:

- To analyse the challenges facing agriculture today and in the future.
- To develop a robust and working definition of the concept of agroecology.
- To specify indicators, with evidence from the literature, to determine the benefits of agroecology.
- To evaluate the comparative performance of an agroecological system with that of an intensively farmed system.
- To provide analysis and evidence of a critical review of data to evaluate the benefits of agroecology.

1.2 Introduction and background to research

Food provision has the largest environmental impact of all human activities (Smil, 2000). Industrial food provision negatively impacts ecosystems, resulting in a substantial and irreversible loss of the diversity of life on Earth. 60% of the major 24 ecosystem services examined by the Millennium Assessment have being degraded, possibly irreparably, as food needs are traded off against ecosystem services (MEA, 2005). The unsustainable nature of industrial agriculture can be attributed to its pervasive manipulation of biological, chemical, physical and genetic cycles which have degraded the natural maintenance functions of agroecosystems (Hill, 1998; Welch and Graham, 1999; Lang and Heasmen, 1994). The goals of industrial agriculture have been to maximise production, and to maximise profits (Gliessman, 1998); as far as meeting its goals of production, industrial agriculture is successful. Sustainability has never been a primary goal of conventional agriculture.

The intensification of industrial agriculture focussed on modernising farm sectors through technologically-based growth (McMichael, 2009), has seen extreme growth in food production. Since 1960 food production has risen by, on aggregate, 145% worldwide (Pretty, 2008). The practices that have enabled such growth are: the simplification of farming systems through monoculture row cropping; the use of synthetic chemical pesticides, herbicides, fungicides, insecticides and fertilisers; hybrid and chemically dependent seed varieties; increased scale of operations; mechanised farm labour and irrigation systems; and intensive livestock practices (Pretty, 2008; Hill, 1998; Horrigan et al., 2002; Scrinis, 2007). Subsidies, policies and capital grants have encouraged these productive, yet environmentally damaging practices (Stoate et al., 2001; Pretty, 2003). Concerns are now focused on decreasing yields produced each year, with conventional farms constantly needing to add more and more fertilisers to maintain growth, and more potent pesticides to manage pests. The implication of these practices can be seen in the erosion and degradation of soil; loss of biodiversity; contamination of water and increased dependence on non-renewable resources (MEA, 2005; Hill, 1998; Pretty, 2008; IAASTD, 2009).

The negative externalities of these practices are growing as natural resources are overused, and pollution is generated. Negative externalities are costs that are not paid for by the polluter, instead by those affected by them. Pretty (2008) highlights how negative agricultural externalities are neglected costs, with delayed effects, that damage marginalised groups and are hard to identify. If the costs were borne by the polluter then the efficiency of intensive agricultural systems would be brought into contention. Practices that internalise the externalities, without creating environmental problems would be highly valued (Pretty, 2008).

Pesticides are used to protect crops from pests to reduce loss and to ensure high yields. Pesticide use has risen, as has the variety of pesticides being used, e.g. in the EU there are 800 registered pesticides (Carvalho, 2006). Figure 1-1 demonstrates how agrochemical dependence is initiated as a basic problem solving technique. There is a problem (pests), action is then taken to fix the problem (pesticides). It is a balancing loop, acting as a negative feedback. This practice has become habitual, and accepted. Path dependency is locked-in as the conditions for more and more chemicals are created (Wilson and Tisdell, 2001). Negative externalities are generated and it becomes difficult to reduce the use of these chemicals despite the rising social, economic and environmental costs that they produce (Pimentel, 2005; Pimentel et al., 1997; Pretty et al., 2000).

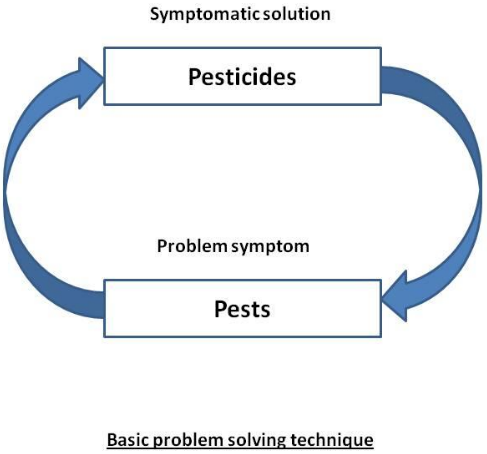


Figure 1-1 Conventional method of solving the crop pest problem: the cycle of pesticide dependence. Adapted from Ehrenfeld, 2008.

Figure 1-2 shows the consequences of unwanted results from pest control. The problem keeps returning, whilst unintended consequences (negative externalities) are created elsewhere. Unwanted effects can increase as focus is directed solely on solving the symptoms of the problem, failing to address the root cause. It is a reinforcing loop, demonstrating positive feedback. The problem is magnified through continued pesticide applications, and the inability to see alternative, sustainable solutions (Edwards-Jones and Howells, 2001). Target pests can become resistant to pesticides over time, which creates a situation where either more applications are required, or stronger strains and concentrations are needed (Wilson and Tisdell, 2001). Pesticides create a disequilibrium in the system, seeping into soils, proving toxic for beneficial biota which play vital roles in ecosystems (e.g. earthworms, fungi etc.). They dominate the structure and the functions of natural systems (Pimentel, 2005).

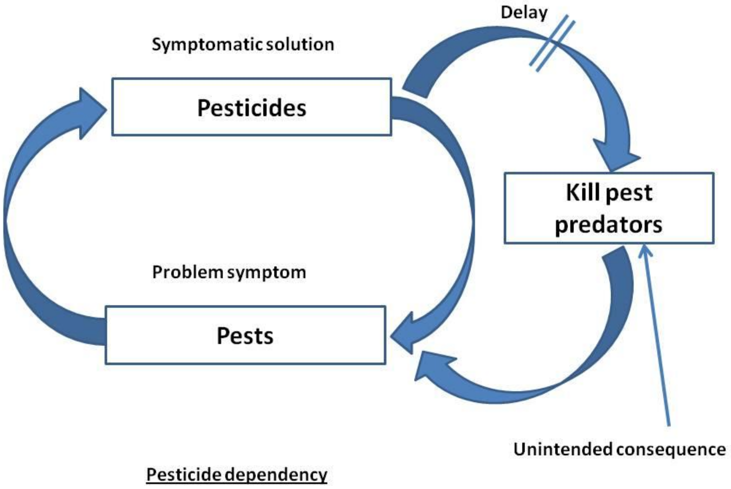


Figure 1-2 The unintended consequence of pesticide use in conventional agriculture. Dependency is locked-in due to the reduction of beneficial pest-predators. Adapted from Ehrenfeld, 2008.

Recent research has been tailored to reduce the unsustainable nature of conventional agriculture, which is demonstrated in Figure 1-3. Genetic engineering, agrochemicals and biotechnology were applied as the most suitable technologies. The ‘green/gene revolution’ solutions promoted are technical and prohibitively costly, putting them out of reach of an estimated 1.9-2.2 billion people who cannot access the complete packages of inputs necessary: modern seeds, water, capital, fertilisers, pesticides (Pretty, 1995). Without all of the aforementioned inputs yields may be no better than with the traditional system, however the farmer will have a much higher financial outlay. ‘Green/gene revolution’ technologies focus on the reduction of limiting factors to cure the symptoms of an unhealthy agroecosystem (Altieri and Nicholls, 2005), the common belief being that low productivity is due to pests and nutrient deficiencies, however these are systemic problems of an agroecosystem in disequilibrium (Carrol et al., 1990). Such reductionist thinking sees new technology that can overcome its own limitations as the main objective of agricultural research, diverting attention from the root causes of such limitations (Altieri and Nicholls, 2005; Altieri, 1989; Vanloqueren and Baret, 2009; Gliessman, 2007).

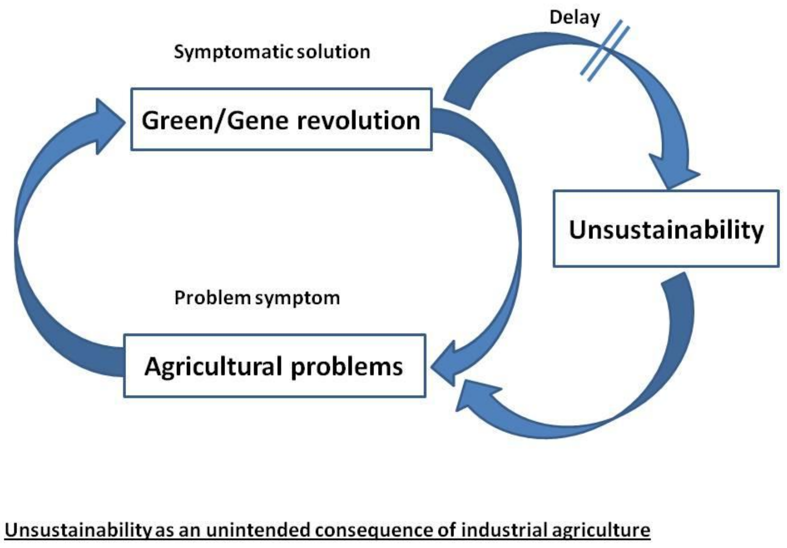


Figure 1-3 Technological regime – the pattern of normal problem solving activities in the progression of agricultural research and development: unintentionally creating unsustainability. Adapted from Ehrenfeld, 2008.

Figure 1-4 shows the dominant method of dealing with unsustainability. By constantly taking ‘the chemical intensive path’ it becomes increasingly difficult to move down to the lower loop of ‘agroecology’. As the present technological fix solutions are not creating the conditions for long-term sustainability, limited resources (e.g. agricultural research and development) are being used up, and in the wrong direction (Ehrenfeld, 2008). Attempts to address the symptoms of agricultural problems are pursued rather than attacking their root causes. The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) calls for a paradigm change in agricultural research and development to increase knowledge and support for agroecological approaches that can tackle the problem of unsustainable agriculture at the root, creating the possibility for long-term productivity and ecological sustainability.

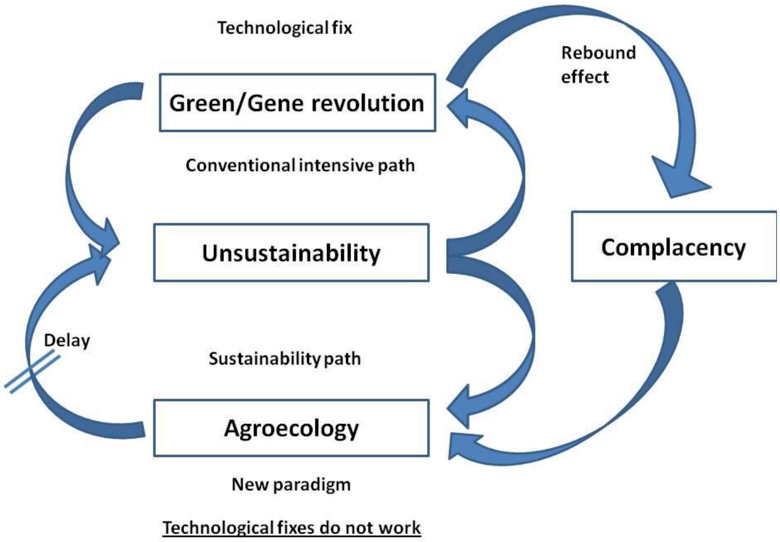


Figure 1-4 Agroecology as a new paradigm for agricultural research and development. Adapted from Ehrenfeld, 2008.

Industrial agriculture, supported by public and private research institutions, has been claimed as the only way to achieve food security. Recent work by IAASTD challenges this thinking, calling for a radical change in agricultural practices. It highlighted the vulnerability of conventional agricultural practices that have degraded ecosystems, preventing them from functioning properly. Damaged nutrient and water cycles have rendered the ecosystems unable to adapt to climatic changes. The report advocated agroecology and sustainable farming to adapt to and mitigate global environmental change. Small farmers and their embodied traditional knowledge were seen to be key resources needing to be protected and utilised to find real site specific solutions to the changing climatic conditions that are predicted to come in the future. The IAASTD report brings into contention the future of mainstream agricultural practices and it opens up the possibility of embracing alternative practices to meet our sustainability needs.

CHAPTER 2

2.1 Literature review

2.1.1 Sustainable agriculture and sustainability

Agriculture is facing a paradigm shift away from a sole emphasis on technological fixes to enable productivity gains to one that embraces sustainability (Heller and Keoleian, 2003; Altieri and Rosset, 2006). Agricultural sustainability centres on the need to be productive without adversely affecting the agroecosystem (Tilman et al., 2002; Altieri 1989). An agroecosystem is an interactive community of flora and fauna managed to produce food, fuel and fibre (Altieri, 2002; Gliessman, 2007). It is understood that agroecosystems depend on both biodiversity (wild and cultivated species e.g. for pollination), and soil biota (determining soil fertility and cycling nutrients to be made available for plants) for their health (Gomiero et al., 2008). Sustainable agriculture confers an ecological approach to the management and utilisation of an agroecosystem to maintain: productivity; regenerative capacity; the ability to perform ecosystem services and processes; and the capacity to adapt to climate change (Lewandowski, 1999; IAASTD, 2009).

Holt-Giminez (2002) stated that sustainability, *"as a property of an agricultural system, is neither static nor deterministic, but probabilistic",* making it only possible to predict the chances that sustainability goals will be met through various management practices. A sustainable agricultural system has the properties of resilience and persistence, which determines both the ability of the system to buffer shocks and stresses and to maintain long term productive capabilities (Pretty, 2008; Conway, 1985). To be sustainable the system must be maintained at a certain state or quality (Heller Keoleian, 2003), evaluated by monitoring trends in certain indicators. Resilience and persistence indicate the probability of sustainability (Gliessman, 1998), whereas vulnerability indicates the probability of unsustainability (Holt-Giminez, 2002).

Defining sustainability is difficult, yet with universal terms such as sustainability and democracy, there is no need to have an absolute definitive. The idea is logical and acceptable, yet the current *modus operandi* is to only pursue sustainability if it is economical to do so. Hill (1998) defines sustainability as the *"maintenance of the* *planet, it’s ecosystems, society and its communities, for optimal equitable environmental and human health and well being”.* For Hill (1998) the object of sustainable initiatives is to concentrate on ecosystems and human welfare, referring to absolute necessities to maintain: water, air, nutrients and freedom from pollutants for now and future generations. Economics, from this line of thinking is merely a tool to allow us to create lives that meet our higher goals; it is a means, not an end goal. Economics is useful to evaluate the costs and benefits of actions, yet is insufficient as a basis of values to make wise decisions (Hill, 1998).

The goal of ecological sustainability is to maintain global ecosystems, which provide us with all the useful resources we need for inputs, and act as sinks for our waste, therefore the ecological dimension of sustainability is the foundation of overall sustainability, and is a precondition for both the social and economic dimensions (Van Der Werf and Petit, 2002). Taking ecological sustainability as the most important goal sustainable agriculture has to be judged on its ability to protect and maintain natural capital, whilst maintaining and enhancing food production.

2.1.2 Agroecology

“Agroecology provides a robust set of solutions to the environmental pressures and crises facing agriculture in the 21st century”(IAASTD, 2009). Agroecology is the scientific theory of sustainable agriculture. It is defined as a holistic method of designing productive agricultural systems that rely on minimal inputs of agrochemicals and energy. Instead, it relies on *“ecological interactions and synergisms between biological components to produce mechanisms to enable the systems to boost their own soil fertility, productivity and crop protection”* (Altieri, 1995). Agroecology is a system of agricultural production that maintains the biological diversity of healthy ecosystems, including soil, plants, animals, and people. ‘Organic’, ‘regenerative’, ‘ecological, and ‘low-input’ are other terms used to describe alternative agroecological practices. The approaches differ from conventional agriculture in the natural methods used to build soil fertility and to fight pests and diseases. Many different practices are used including crop rotations, polycultures, agroforestry, cover crops, biological pest management, animal integration, aquaculture and integrated nutrient management. The goal is to promote productive soils, robust ecosystems and healthy people, whilst reducing and

removing negative environmental impacts. Agroecologists attempt to combine modern agricultural science and indigenous knowledge systems to increase food security, and conserve natural resources (Altieri, 1995; Gliessman, 2007).

As a scientific approach, agroecology is an interdisciplinary, holistic paradigm that links agronomy, ecology, sociology and economics (Dalgaard et al., 2003), which applies concepts and principles of ecology to design and manage sustainable agroecosystems (Altieri, 1995; Gliessman, 1998). Its primary aim is to solve the sustainability problem of present agriculture, meeting food production needs without adversely impacting the environment or society (Altieri, 1989; Gliessman, 1998).

In comparison with conventional farms, which are viewed as food producing units with inputs and outputs, the farm is looked at as an ecosystem with both environmental and social aspects (Altieri and Nicholls, 2005), on this scale, agroecology aims to develop alternative low-input systems that are productive and not dependent on agrochemical and non-renewable inputs. Complex ecological systems are developed that interact, creating synergisms between components that build soil fertility, productivity and crop protection (Gliessman, 1998). The objective of agroecology is not to improve one part of the farm, but to make every part work well by improving the whole agroecosystem (Liang, 1998). The first step in the agroecological transition is the removal of harmful inputs, finding biological substitutes; organic agriculture is often at this stage (Guthman, 2000). To move to the next level there is a need for increased management skill to generate fertility through crop rotations, green manures, legumes and integrated pest management; (via increased diversity, healthy soils and the encouragement of beneficial insects that predate the pests). Collaboration is central to transfer knowledge, spreading best practice. To enable synergisms to flourish redesign of the agroecosystem is the overall goal (Hill, 1998).

An agroecological farm system has the normative goals of productivity, stability, sustainability and equitability (Carroll, 1990; Altieri, 1995).

Productivity: in terms of the efficient use of resources, in the input to output ratio. *Stability*: in the farm system to ensure the continuation of production during environmental (e.g. pest, climatic) disturbances.

Sustainability: in terms of the ability of the system to persist through the maintenance, conservation and regeneration of the resource base which the farm depends on.

Equitability: through the even distribution of benefits from the farm, and to how far farmers have been involved in the formulation of research agendas and their active involvement in the process of technological innovation and collaboration (Altieri, 1995).

An agroecological approach (see Figure 2-1) is the recognition of agriculture's multifunctional dimensions in facilitating progress towards sustainability goals by:

- strengthening resilience (social, ecological, economic) in the face of global environmental change; focusing on nutrition and health and reducing pesticide use; conserving natural resources (biodiversity, soil organic matter, water quality, ecosystem services);
- stabilising economies (diversifying farm income sources; reducing the vulnerability of single commodity price swings);
- mitigating global environmental change by increasing energy-efficiency, reducing fossil fuel based inputs, promoting the sequestration of carbon and water capture in soil;
- increasing social resilience, community cohesion and institutional capability (promoting ecological literacy and social networking).

Adapted from IAASTD (2009)

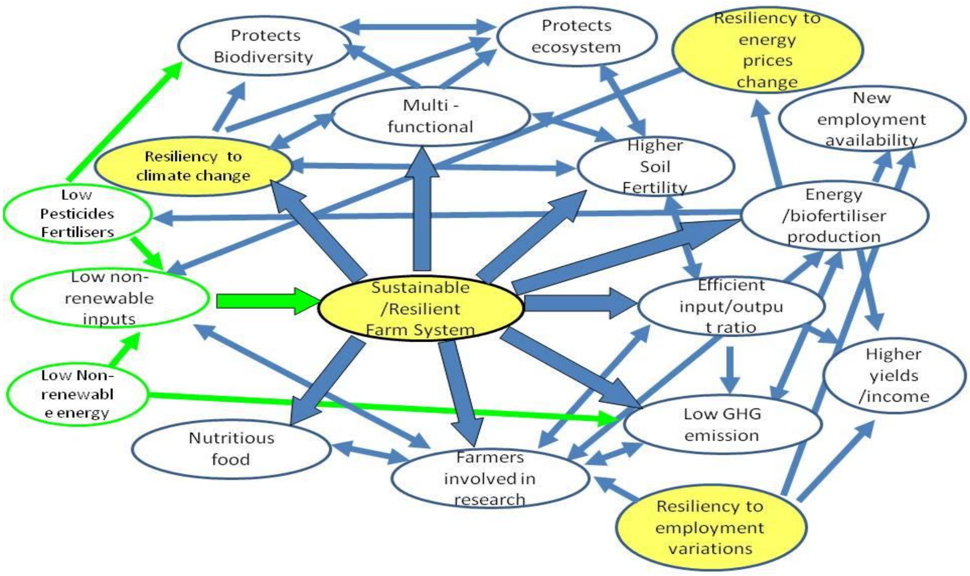


Figure 2-1 The multifunctional dimensions of sustainable farm system goals. Inputs in green, thick blue arrows show key concerns, thin blue lines showing interconnectivity.

2.1.3 Indicators of sustainable agricultural practices

Ever since the Rio Summit (UNCED, 1992) there has been a need to construct indicators to monitor progress towards sustainable development, to validate those practices that lead towards more sustainable systems, whilst identifying unsustainable practices (Lefroy et al., 2000). An indicator is a constructed variable that describes an element of a complex system (Castoldi and Bechini, 2009). A key characteristic of an indicator is its ability to summarise the main aspect of the system in focus (Fernandes and Woodhouse, 2008). The benefits of using indicators is that conclusions can be quickly made which can help researchers to identify trends and to calculate the possible impacts of specific agricultural practices on sustainability (Bockstaller et al,. 1997). Once indicators have been selected trends can be monitored to assess if they are stable, increasing or decreasing. At the farm scale indicators can assist farmers to improve the sustainability of their practice by acting as a decision-aiding tool (Pervanchon, et al., 2002).

There is widespread recognition, amongst agricultural researchers, that sustainable agriculture is essential creating a need to design appropriate tools to evaluate and assess sustainability (Pacini et al., 2003). The creation of these is seen as a necessity to operationalise sustainable agriculture (Hansen, 1996). Indicator sets developed include: Environmental Management for Agriculture (EMA) (Lewis and Bardon, 1998); Ecopoints (EP) (Mayrhofer et al., 1996); SOLARGO (Pointereau et al.,1999); Agro-Ecological Indicators (AEI) (Girardin et al., 2000); Life Cycle Assessment (LCA) (Heijungs et al., 1992); and Indicators of Farm Sustainability (IFS) (Vilain, 1999).

A major challenge involved with the evaluation of agricultural sustainability is the fact that the parameters vary across the different aspects of sustainability (Rigby and Cáceres, 2001; Girardin et al., 2000). The primary objectives of sustainable agriculture are: to maintain high yields whilst limiting pollution and degradation of soil, water and air; to conserve non-renewable resources; to conserve biodiversity and to protect the landscape. Agroecosystems need to maintain biodiversity and the function of effective nutrient cycles, therefore indicators of sustainable agriculture need to be directed to promoting these principles (Edwards et al., 1993).

2.1.4 Soil quality: an indicator of agricultural sustainability

Soil is a vitally essential element of the earth’s biosphere and one of the environment’s most important resources, playing a key role in many ecosystem functions and services, including carbon, nitrogen and water cycles (MEA, 2005). Efforts have been made to place monetary value on the services provided by soil biota; globally it has been estimated to exceed US $1.5 trillion (Pimental et al., 1997). Soil degradation is a major threat to long-term food productivity, reducing yields on approximately 16% of agricultural land in Africa and Central America (Wood et al., 2000). The UN estimated that by 2050 half of the world’s arable land will be unfit to farm, already 2 billon hectares of soil are classified as degraded (UNEP, 2002). It is doubtful whether intensive farming practices can be sustained, due to the loss of soil quality and the erosion of soil, therefore alternative practices that can produce a good yield, whilst protecting and regenerating the soil are urgently needed (Tilman, 1998).

Soil management determines the fundamental interface between farm systems and the environment (Doran, 2002; Marinari et al., 2006) and a healthy soil is the foundation of a sustainable food system (FAO, 2005). Maintaining soil fertility is seen as the essential indicator of sustainable land management and agricultural sustainability (Mäder et al., 2002; Doran and Zeiss, 2000; Doran, 2002). Fertile soil enhances the productivity of plants, but also affects environmental quality, impacting on water and air quality (Doran, 2002). The quality of the soil indicates sustainability, determining the health of animals, plants and humans (Haberen, 1992; Altieri and Nicholls, 2003; Sanchez and Swaminathan, 2005).

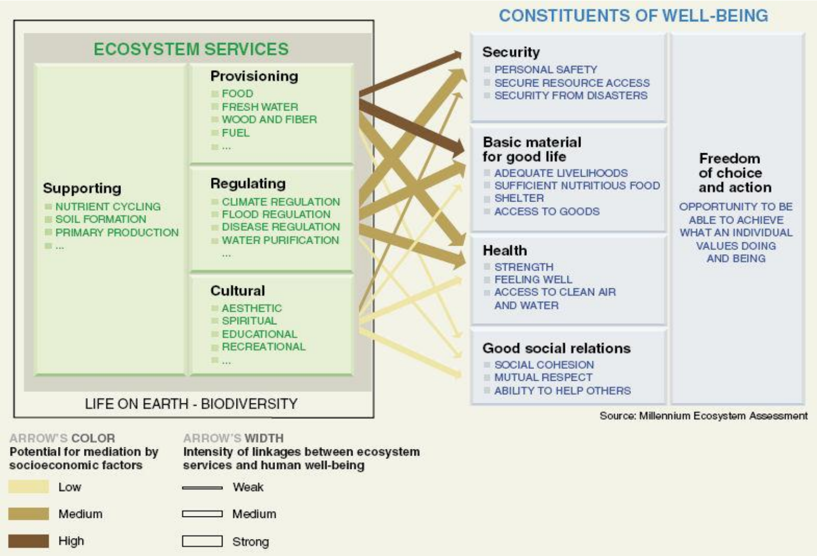
Soil is a dynamic living system with biological, chemical, and physical properties, which interact through various synergistic processes, to maintain the effective cycling of nutrients and minerals (Shannon et al., 2002; Karlen et al., 2003; Doran and Parkin, 1994). Soil plays a key role in ecosystem services through the holding and releasing of water; decomposition of plant and animal residues; transformation and cycling of nutrients; sequestration of carbon; and the promotion of plant health through the suppression of plant-pathogenic microbes and phytophagous fauna (Doran and Zeiss, 2000). Agroecological farm systems seek to reduce synthetic fertilisers making them dependent and reliant on the nutrient transformation processes of fertile soil as an essential dynamic in their productivity (Fließbach et al., 2007; Drinkwater et al., 1998).

To assess whether the benefits of agroecological farming practices can contribute to soil quality, and therefore agricultural sustainability, it is necessary to examine the effects of such practices over time (Bending et al., 2004). The assessment of soil health and the direction of intertemporal change is a primary indicator of sustainable land management (Doran, 2002).

2.1.5 Biodiversity: an indicator of agricultural sustainability

Biodiversity makes life on earth possible; it encompasses all the species, food chains, and biological patterns in the environment (Paoletti, 1999). Biodiversity affects the properties of ecosystems, influencing the ecosystem services which provide benefits to humans (Diaz et al., 2006). Figure 2-2, demonstrates the clear links between biodiversity, ecosystem services and human well-being. Ecosystem functions are defined as "*the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly*" (De Groot, 2002). All of our medicines, food, fibre and fuel have come from various natural organisms. Ecosystems provide services through pollination, seed dispersal, regulation of climate, biomass production, nutrient and water-cycling and soil formation; the value of which has been estimated to be US $33 trillion a year (Costanza et al., 1997). If we want a sustainable agriculture we need to preserve ecosystems services by protecting and restoring their biotic integrity (Dahlberg, 1994; Esquinas-Alcázar, 2005; Thrupp, 2000). The loss of biodiversity from current intensive farming practices is unsustainable; to become sustainable, agricultural practices need to promote biodiversity (Hole et al., 2005) linking agroecology and biological conservation (Scherr and McNeely, 2008).

In the developing world dietary requirements are often made up from local sources, where vitamins, proteins and medicines are available from hunting and gathering. These 'biodiversity-dependent ecosystem services' (Diaz et al., 2006) are vital for the poor, losing these services increases their vulnerability. Poverty is therefore linked to biodiversity loss, as ecosystem services degrade and well-being decreases (Esquinas-Alcázar, 2005). Sustainable agricultural practices which can protect biodiversity and ecosystem services will be of great use for the 1 billion subsistence farmers who live in biodiversity ‘hot spots’, which are some of the most threatened species-rich areas in the world (Scherr and McNeely, 2008).



Source: Millennium Ecosystem Assessment

Figure 2-2 Ecosystem services, biodiversity and human well-being (MEA, 2005).

Recent work has shown how an increase in species diversity increases the stability of a natural ecosystem over time (Díaz and Cabido, 2001; Tilman et al., 2006). Agricultural systems supporting a greater diversity of species are thought to reduce vulnerability by building resilience (Gunderson and Holling, 2002; Fraser et al., 2005). Climate change is forecasted to alter rainfall and temperature unevenly throughout the world. Effects predicted include extreme droughts in semi-arid areas, severe flooding in low-land areas and increased periods of excessive heat (Cline, 2007). The predicted variations will vary from crop to crop and from region to region, but it is thought that the developing world will be most severely affected. The interactions between high levels of CO_2, temperature and soil moistures are critical criteria for crop yields (Hanson et al., 2007). To be sustainable, future agricultural production systems must possess an inherent capacity to adapt to changing climatic conditions. Building up diverse systems, which incorporate biodiversity and crop diversity is a necessary strategy.

Crop and genetic diversity provide options for the future. Reservoirs of alternative crops, with varying characteristics reduce the vulnerabilities farmers face from changing climatic conditions, new strains of pests and diseases. The resistant properties some crops have, which lay redundant, can prove crucial to fight fungal diseases etc. Biodiversity protection is thus a sustainability, conservation and development strategy, building up food security, maintaining future options.

2.1.6 Resource efficiency: an indicator of agricultural sustainability

The environmental impact of energy use in agriculture concerns the dependency on non-renewable fuels and the pollution emitted by their use (Pimentel et al., 1983). International government policy supports the reduction of carbon emissions and green house gases (GHG) to mitigate climate change. The Intergovernmental Panel on Climate Change stated that agriculture contributes 20% of the total global GHG emissions, 90% of which comes from the production of agrochemicals and machinery (IPCC, 2001). It is estimated that it takes between 6-10 times more energy to produce a ton of cereals or vegetables from energy intensive industrial agriculture, than with sustainable agriculture (Saunders, 2004). Carbon is emitted through the direct energy used in the production system, the indirect embodied energy used in inputs and their manufacturing, and the cultivation of soils, contributing to soil erosion (Pretty et al., 2002). Agriculture also plays a key role in mitigating climate change through the potential of carbon sequestration from organically managed soils. Techniques that both reduce the creation of GHG's and lock up carbon into soil will be valuable for consideration in these efforts.

Reducing the use of fossil fuels and non-renewable resources and their coupled GHG emissions is a challenge for the transition to agricultural sustainability. Diverse factors can be evaluated to compare farming systems' economic performance (Stolze et al., 2000), energy efficiency can be calculated and nutrient balances can be worked out to guide management decisions (Fließbach et al., 2007; Hansen et al., 2001). Dalgaard et al., (2001) created a model that can be used to assess the energy use of different farming systems, which is one indicator of sustainability. The energy balance is the ratio of total external inputs to outputs. Outputs include yields, GHG emissions and nutrient outflow, e.g. nitrogen leaching (Smith et al., 2008). There are difficulties in measuring the negative externalities from a farm system: for example the effects of pesticides on biodiversity can be largely unknown. Economic valuations can be placed on some ecosystem services, for example Pimentel et al., (1997) estimated that the service honey bees and wild pollinators provide, to US agriculture, was worth US $40 billion a year.

Conventional agricultural systems are heavily dependent on non-renewable fossil fuels to boost productivity and to suppress pests. As fossil fuels stocks become depleted the costs of production of synthetic fertilisers will increase, impacting the performance of intensive agriculture (Gomiero et al., 2008). Alternative techniques to enhance crop productivity and reduce pests without negatively impacting on the environment will become more sought after (Altieri and Nicholls, 2003). Globally 3 billion kg of pesticides are applied annually, predominantly due to the use of intensive monocultures which suppress the potential for species interactions which would naturally regulate the level of nutrient cycling and pest populations (Pimentel, 2005). By reducing non-renewable inputs and designing out toxic agrochemicals, agroecological systems can improve the environmental quality of the farm, whilst making the farm more financially secure and efficient, and therefore more sustainable (Pimentel et al., 2005). To achieve the desired reduction integrated pest management systems and nutrient cycling systems can be put in place that can retain high yields of crops, whilst reducing the costs, environmental and economic, of agrochemicals.

A key challenge is to increase yields whilst reducing synthetic inputs. Smil (2001) estimates that 40% of the world's population depend directly on synthetic nitrogen for their food needs. However nitrogen fertilisers have been linked to serious environmental hazards, such as marine eutrophication, global warming and groundwater contamination (Crews and Peoples, 2004). The lower yields found in organic systems are thought to be due to the lack of nitrogen available for the crop, as synthetic nitrogen fertilisers have caused the dramatic increase in yields witnessed during the 20th century. Strategies to incorporate more nitrogen into the soils organically are being studied to determine how to address this problem (Rao and Mathuva, 2000; Smith et al., 2008; Hanson et al., 2007; Drinkwater et al., 1998). Changes in fertility management are thought to be beneficial as are different cultivar choices (Hsu et al., 2009). Promoting legumes through inoculation of clover seeds before cropping is another strategy being investigated (Zahran, 1999).

2.1.7 Comparative evaluations of alternative farming systems

There have been a number of long-term field experiments, conducted on a large scale, to compare organic farming with conventional farming practices in a scientifically rigorous manner, that is both relevant and systematic: DOK Experiment (bio-Dynamic, Organic and Konventional) (Mäder et al., 2002; Mäder et al., 2006; Fließbach et al., 2007), Sustainable Agriculture Demonstration Project (SADP), USDA-Agricultural Research Service (ARS) (Teasdale et al., 2007), Rodale Farm System Trial (FST) (Hepperly et al., 2006; Pimentel et al., 2005), Frick reduced tillage trial (Berner et al., 2008), and the Scheyern Experimental farm (Ruhling et al., 2005). Through long-term testing of different combinations of dynamic crop rotations, organic nutrient applications, reduced tillage practices, and legume crops to fix nitrogen, these experiments have sought to demonstrate how different practices can maintain soil fertility, prevent erosion, sequester carbon and increase biodiversity without the use of pesticides and synthetic fertilisers, whilst recording the corresponding effect on yield.

These field trials have calculated the carbon sequestration potential for different farming practices, clearly demonstrating how sustainable agricultural techniques, that build soil organic matter, can reduce the overall GHG emissions generated by agriculture. Organically managed soils can sequester 200 kg of CO_2 per hectare per year (Fließbach et al., 2007), demonstrating how sustainable agriculture could become a key strategy to mitigate climate change.

The SADP carried out a 9 year comparison of selected minimum-tillage strategies for grain production to assess whether organic cropping systems with organic amendments could increase soil carbon, nitrogen, and yield potential more than conventional no-tillage (Teasdale et al., 2007). Birkhofer et al., (2008), working on the 28 year DOK trial in Switzerland examined the effects of different farm systems, intensive and agroecological, on the interactions between soil, microorganisms and aboveground fauna. They sought to determine whether agroecological management of soil could contribute to soil fertility and pest control, thereby highlighting how alternative farming practices can help to reduce the negative environmental impacts of intensive farming.

Badgley et al., (2007) collated data from 293 cases that have compared conventional methods with low-intensive methods to test the assumption that yields are always lower under organic management. They estimated that organic production could meet global supply needs. Their work also assessed the amount of nitrogen that could be fixed from leguminous cover crops to replace or reduce the use of fertilisers. Badgley et al., (2007) estimated that leguminous fixing crops could produce 140 million tonnes of nitrogen, which is 58 million tonnes more than the 82 Million tonnes of synthetic nitrogen fertiliser used globally in 2001.

To assess the energy element of agricultural sustainability Gomiero et al., (2008) carried out a comparative study of energy efficiency in organic and conventional farm systems. They also assessed the environmental impacts of both systems, concluding that organic farms perform better in terms of negating environmental impacts. Holt-Giminez (2002) measured the resistance of agroecological farm systems to extreme climatic shocks, in comparison to conventional farms, to study the resistance, seeking to identify the level of sustainability conferred through various farming practices. This work is important due to the changing climate that could bring unpredictable and severe weather conditions. Lessons from agricultural systems that can resist such shocks and still remain productive will be of utmost importance, especially in the developing world where the changing climate is predicted to be most severe.

2.1.8 Conclusion

Agroecology is the science of sustainable agriculture and has a vision of how to create long-term productive agroecosystems without damaging the resource base. It has been demonstrated that an agroecological approach to agriculture has the potential to link conservation, development and sustainability goals. Soil, biodiversity, energy efficiency and yields are indicators that can be used to assess the benefits of sustainable agricultural practices and the weighting of these indicators is determined by the vision of sustainability of those carrying out the assessment. For long-term productivity it has been demonstrated that ecological sustainability is essential and therefore the indicators need to be weighted correspondingly to ensure we retain our long-term productive capabilities.

CHAPTER 3

JOURNAL PAPER

Agriculture, Ecosystems and Environment

Agricultural challenges today and in the future: the beneficial role of agroecology

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3.1 Abstract

Interest in agroecology is growing as evidence mounts that conventional agricultural methods are unsustainable, degrading the resource base (e.g. soil, water, crop diversity, biodiversity etc.) on which they depend. Alternative ways to produce foods that build soil fertility, protect ecosystems, conserve biodiversity and reduce energy inputs, provide the possibility of long-term productivity and ecological sustainability. The International Assessment of Agricultural Science and Technology for Development (IAASTD) have supported agroecology as a key set of solutions for world agriculture, which synergistically tackle development, sustainability and conservation goals. This study presents indicators to measure the sustainability of an agricultural practice which, when placed in a hierarchical pyramid, demonstrate their importance and interconnected relationships. A comparative evaluation of agroecological and conventional systems is shown to assess the effects of management practices on the indicators. Agroecological approaches differ from conventional ones as they aim to sustain the soil and ecosystems by reducing synthetic inputs and creating alternative natural processes to maintain soil fertility and manage pests. Soil fertility is the essential indicator of sustainable agriculture, it was found to improve in agroecological systems, indicated through increased soil microbial biomass (60% higher than in conventional agriculture) and earthworm abundance (up to 88% higher than in conventional agriculture). The loss of biodiversity due to current intensive farming practices is an indicator of unsustainability. In the agroecological systems biodiversity was shown to be comparatively higher. The diversity of bird and beetle species were recorded to be 50% and 38% more abundant respectively, and bat activity was shown to be 60% higher. These are bio-indicators of sustainable agriculture. The reduced chemical inputs led to an average of 50% less energy used on the agroecological systems. The resulting effects on yields showed great variation. One long term trial showed a 20% yield reduction in the agroecological system. Yet in times of drought, when advanced cropping systems were implemented, in developing countries yields were shown to be comparable, often significantly higher. This study provides solid evidence that the world’s future food security lies in the hands of sustainable agricultural practices. Agroecology demonstrates techniques that can be used towards reaching this vital goal.

Keywords: Agroecology; Sustainable Agriculture; Sustainability Indicators; Soil fertility; Biodiversity; Energy Efficiency.

3.2 Introduction

There are challenges and vulnerabilities facing agriculture in the 21st century. There is an increasing population requiring high amounts of nutritious food, there are problems of scarce resources (fossil fuels, water, soil etc.), threatened ecosystems, loss of biodiversity, climate change, and an understanding that current production techniques are unsustainable. The International Assessment of Agricultural Science and Technology for Development (IAASTD) has, after a 4-year study, called for a more holistic approach to farming. The panel of 400 international experts have been compared with the Intergovernmental Panel on Climate Change, for the quality of governance and the importance of the recommendations. They concluded that a radical change in agriculture is needed and that *"agroecology provides a robust set of solutions to the environmental pressures and crises facing agriculture in the 21st century"* (IAASTD, 2009).

Agroecology is defined as a holistic method of designing productive agricultural systems that rely on minimal inputs of agrochemicals and energy, relying instead on *"ecological interactions and synergisms between biological components to produce mechanisms to enable the systems to boost their own soil fertility, productivity and crop protection"* (Altieri, 1995). Agroecology is understood to have a set of solutions to the problems facing agriculture; it has the theoretical basis to design food production systems that can maintain long-term productivity, which equates to long-term food security.

Agroecology is an emerging paradigm, presenting the scientific theory and vision of sustainable agriculture. Because agroecology is a relatively new discipline there have been no long-term studies to date that demonstrate the full potential of agroecology in the western world. Organic farming is one practice of agroecology; therefore there is a wealth of long-term trials comparing organic farming with conventional farming. Organic farming is an agroecological approach to farming as it aims to sustain the soil and ecosystems, by reducing synthetic inputs and creating alternative natural processes to build soil fertility and manage pests.

There are many differences between organic practices. Guthman (2000) sought to determine how far organic farmers in California followed agroecological ideals. It was discovered that although growers followed some of the agroecology principles they had not reached the 'redesign' phase, where the farm is working in a balanced, self-regulating manner. Organic farming is often only at the input substitution phase of agroecology and there is still more work to be done to enable organic systems to become more sustainable.

3.2.1 Sustainability indicators

It is understood that in order for agroecology to contribute to sustainable agriculture it must establish a framework for measuring and quantifying sustainability (Gliessman, 2007). Measuring sustainability is a complex issue full of difficulties, as it is very difficult to monitor and to account for agricultural externalities (Pretty, 1995; Tietenberg, 2006). There are however some crucial elements that are essential for long-term ecological agricultural sustainability: soil quality; biodiversity and ecosystem protection; resource efficiency and high yields of nutritious food.

Maintaining soil health is seen as the essential indicator of sustainable land management and agricultural sustainability (Mäder et al., 2002; Doran and Zeiss, 2000; Doran, 2002). Fertile soil affects the productivity of plants, but also affects environmental quality and has impacts on water and air quality (Doran, 2002). The quality of the soil indicates sustainability, and determines the health of animals, plants and humans (Haberen, 1992; Altieri and Nicholls, 2003; Sanchez and Swaminathan, 2005).

Biological diversity makes life on earth possible as it includes all the species, food chains, and biological patterns in the environment (Paoletti, 1999). Biodiversity affects the properties of ecosystems, and influences ecosystem services, which provide benefits to humans (Diaz et al., 2006). Agro-biodiversity and crop diversity are key resources for future food security, seen as crucial reservoirs of genetic options to adapt to climate change (Esquinas-Alcázar, 2005; Thrupp, 2000) The loss of biodiversity from current intensive farming practices is unsustainable, eroding the genetic resources that are the basis of the food chain; to become sustainable agricultural practices need to promote biodiversity (Hole at al., 2005; Esquinas-Alcázar, 2005).

Conventional agricultural systems are heavily dependent on non-renewable fossil fuels to boost productivity and to suppress pests. As fossil fuel stocks become depleted the costs of production of synthetic fertilisers will increase, impacting the performance of intensive agriculture (Gomiero et al., 2008). By reducing non-renewable inputs and designing out toxic agrochemicals, agroecological systems can improve the environmental quality of the farm, whilst making the farm more financially secure and efficient, and therefore more sustainable (Pimentel et al., 2005).

3.2.2 Comparative evaluations of alternative farming systems

Long-term field trials allow the detailed study of various agricultural techniques on soils, biodiversity and yields. They are important as they provide insights into the links between long-term productivity of farming systems and their management of soil fertility. These studies also generate an understanding of the complex ecological interactions and processes that aid in the development of alternative agricultural systems. The knowledge and data generated from the trials is important for agroecological systems as they depend on ecological interactions for their productivity and stability.

Detailed comparisons of organic and conventional agriculture have been made using soil indicators such as microbial biomass and earthworm abundance (Birkhofer et al., 2008; Mäder et al., 2002; Drinkwater et al., 1998; Fraser et al., 1998); biodiversity, using bio-indicator species abundance, e.g. bats, spiders, beetles (Hole et al., 2005; Brussaard et al., 2007; Mäder et al., 2002; Reaganold et al., 1993; Pfiffner and Niggli, 1996) and energy, using indicators of energy and resource efficiency in comparison with yield performance (Pimentel, et al., 1983; Gomiero et al., 2008; Wood et al., 2006; Daalgard et al., 2001). Work on the effects of legume based cropping systems were shown by Drinkwater et al., (1998) who reported on a 15-year study at the Rodale Institute, Pennsylvania. Conventional systems using fertilisers and pesticides were compared with organic systems using organic residues and diverse cropping systems to maintain soil fertility, whilst producing high yields. The effects of crop diversity on yields were recently carried out by Smith et al., (2008) at the Kellogg Biological Station. No fertilisers or pesticides were used in the 3-year experiment which demonstrated how diverse systems compare to monocultures, showing how yields were increased in a linear fashion in relation to the number of crops in rotation. Their investigation was based on the ecological theory that increased species diversity benefits ecosystem functions. The effects of agroecological farming practices in the developing world has been thoroughly documented by Pretty et al., (2006). They demonstrated how agroecological interventions affected yields, pesticide use, carbon sequestration, and water productivity on 286 farms, in 57 countries, covering 37 million hectares (3% of the cultivated land in the developing world).

This research aims to evaluate whether agroecological systems can meet the challenges faced by agriculture in comparison with conventional practises. Using long-term field trials and peer reviewed journals, evidence and data were collated to make a comparative evaluation of agroecological farming systems with conventional farming systems to measure the benefits of one system over the other. The data is relevant as it shows clearly how energy efficiency, soil fertility, biodiversity and yields are affected through a comparison of agroecological and intensive farming practices. On the basis of the literature and findings from the data a pyramid was created to demonstrate the hierarchical interrelationships between indicators of ecological sustainability. The pyramid takes into account the problems of sustainable agriculture and the need to compare different agricultural systems to evaluate the overall benefits.

3.3 Methods

Literature was screened for potential indicators of sustainable agriculture. Indicator systems were found to have a predominantly short-term perspective that was not always representative of the goals of long-term ecological sustainability, with relatively equal weighting of economic, environmental and social indicators. As both the social and economic sides are conditioned on the ecological sustainability of the system a new indicator system was developed. ~~Therefore a~~Bioindicators of sustainable agriculture were researched, and a hierarchical pyramid was created that represented the interrelationships between these indicators of sustainable agriculture,~~ that~~ taking~~es~~ into account the major challenges facing agriculture today and in the future. With this system, data to represent the indicators were collected, to make a comparative evaluation of agroecological and conventional agriculture. This paper examines current farming practices by incorporating published data from long-term field experiments and detailed studies of the impacts of different farming practices on the bioindicators; soil, biodiversity, yields and energy. Table 3-1 was created with data from the literature that was averaged to establish a common percentage scale to give the comparison more clarity. ~~The d~~Data was chosen to reflect the indicator system, using prominent long-term farm studies that compared organic and conventional ~~farms~~practices. The positive numbers e.g. ‘Biodiversity - Earthworms +88’ demonstrate the percentage increase of earthworms monitored on an organic system in comparison with a conventional. There were 88% more earthworms. With the example of ‘Yield comparison on a mixed farm -17’, there was a 17% negative difference between the organic and conventional. Yield was shown to be 17% lower on the organic plots.

3.4 Results

Table 3-1 Presenting a quantitative demonstration of sustainability indicator performance of organic systems in comparison with conventional

Indicators	Organic as % of conventional	Sources
Energy efficiency comparison	+58	Mäder et al., 2002
	+63	Wood et al., 2006
	+10/+75	Gomiero et al., 2008
	+22/+72	Hansen et al., 2001
	+50	Daalgard et al., 2001
Nutrient input – Nitrogen total	-30	Mäder et al., 2002
Nitrogen soluble	-70	Mäder et al., 2002
Phosphorous	-39	Mäder et al., 2002
Potassium	-45	Mäder et al., 2002
Pesticide	-98	Mäder et al., 2002
	-50/-65	Pimentel et al., 2005
Yield comparison – mixed farm	-17	Mäder et al., 2002
Legume based cropping system	-1	Drinkwater et al., 1998
	-5/-10	Lotter et al., 2003
Mixed farm	-23	Birkhofer et al., 2008
Increased crop diversity	+100	Smith et al., 2008
Under drought conditions	+79/+90	Lotter et al., 2003
In developing countries	+64	Pretty et al., 2006
Soil – Microbial biomass	+60	Mäder et al., 2006
	+10/+26	Fraser et al., 1998
	+50/+63	Birkhofer et al., 2008
Soil – Bacterial biomass	+33	Birkhofer et al., 2008
Soil fauna	+50	Birkhofer et al., 2008
Biodiversity – Earthworms	+23/+69	Mäder et al., 2006
	+88	Reaganold et al., 1993
	+50	Birkhofer et al., 2008
Biodiversity – Spiders	+50	Pfiffner and Niggli, 1996
	+44	Birkhofer et al., 2008
Above ground biota	+50	Mäder et al., 2006
Beetles – species richness	+38	Hutton and Giller, 2003
Birds – species richness	+50	Beecher et al., 2002
Birds – overall abundance	+61	Beecher et al., 2002
Total bat activity	+61	Wickramasinghe et al., 2003
Bat foraging	+84	Wickramasinghe et al., 2003

3.4.1 Soil fertility

Soil fertility was higher in plots that did not use agrochemicals. Organic farm systems rely on fertile soils, so their actions focus on building soil organic matter and encouraging nutrient cycles to feed the crops. The results show that reducing pesticides and fertilisers positively increases soil microbial biomass in organic farming systems. Findings ranged from 10-23% increase (Fraser et al., 1988) to 60% (Mäder et al., 2002). In the DOK trial in Switzerland Birkhofer et al., (2008) reported an increase of between 50% and 63% in the organic plots in comparison with the conventional methods. Mäder et al., (2006) reported similar findings, showing 40 tonnes per hectare of soil microbial biomass in the organic farm and 24 tonness per hectare on the conventional. The results show that conventional management practices, especially the use of synthetic fertilisers and pesticides, negatively affects the microbial biomass of soil, a prime indicator of soil fertility.

Marinari et al., (2006) chose chemical and microbiological properties as indicators of soil quality to measure. They took samples at certain depth intervals, on an organic (7-year certified) and an intensively managed conventional farm. Their study demonstrated an improvement in soil nutritional and microbiological conditions on the agroecological farm, with higher levels of nitrogen, nitrate, and phosphorous, with an improved microbial biomass content (Marinari et al., 2006).These are recognised indicators of changes in diverse farm systems (Bending et al., 2004). Marinari et al., (2006) showed that agroecological management over 7 years had positively affected soil fertility, by closing nutrient cycles, protecting environment quality and enhancing beneficial biological interactions and processes. They attributed this to versatile crop rotations and a reduction in synthetic agrochemicals. Other studies showing similar results also support these conclusions (Shannon et al., 2002; Hansen et al., 2001).

In summary, the indicators of soil quality in agroecological farm systems have shown positive increases in soil biota, microbial biomass, soil organic matter and nutrient availability. Increases have come primarily from the application of manure and elimination of synthetic pesticides and fertilisers, which support the view that organically managed soils promote the biological cycles of nutrient regeneration. Soil organic matter improves the soil’s water retention capabilities and is a key feature in the water cycle. Additionally there is a demonstrated increase in aboveground fauna which actively control pests on crops, alleviating the need for herbicides and insecticides. Agroecological techniques are proven to improve soil quality making them key strategies to combat soil erosion, soil degradation, whilst reducing the need for pesticides and synthetic fertilisers.

3.4.2 Biodiversity

The data shows that by focussing on the reduction of agrochemicals there are indirect effects as positive externalities are generated. Biodiversity is shown to improve under this reduced chemical management system. Earthworm populations were higher by 23-88%, above ground biota was recorded to be 50% higher, bird species richness was seen to be 50% more abundant. Bat foraging activity was reported to be 84% higher on organic farms. Bat activity is indicative of sound management, as bats are a bio-indicator of environmental change (Wickramasinghe et al., 2003; Jones et al., 2009).Their species richness is reduced by loss of habitat seen in intensified agriculture where monoculture is predominant, and with the use of agrochemicals and the associated effects of these on water quality and prey availability.

3.4.3 Resource efficiency

Organic agriculture has the goal of reducing pesticides and nitrogen fertilisers. Results show that by focussing on the reduction of these inputs energy consumption can also be reduced. Energy inputs included the production of agrochemicals, machinery, infrastructure, and fuel in the Mäder et al., (2002) study. Differences in methodologies and calculations for this parameter make comparative studies difficult. The degree of this reduction ranged from 22-72% in the Hansen et al., (2002) study, the difference being put down to the indirect energy used in the production of fertilisers. Dalgaard et al., (2001) estimated that if there was a 100% transition to organic agriculture in Denmark energy use could be reduced by 9-51%, with a corresponding decrease of 13–38% of the total GHG emissions. The other large difference documented by Gomiero et al., (2008) showed a 10-70% reduction of energy per unit of land on organic systems, which varied due to the difference in crop cultured, and the farm characteristics. Pimental et al., (2005) reported that in Sweden, Canada and Indonesia there had been government programs that had shown high yields of quality crops were able to be produced with a reduction of 50-65% of pesticide. On average there was an overall energy saving of 50% recorded in organic farms, primarily due to the lack of synthetic fertilisers, pesticides, fungicides and herbicides

3.4.4 Yields

Comparison of the two systems showed considerable variation in yields. Drinkwater et al., (1998) results at the Rodale experiment demonstrated the 10 year average of maize yields were only 1% higher for the conventional system than the organic. Yield was negatively affected by nitrogen leaching which they determined was 60% more for the conventional system than the organic, over 5years. Organic systems leached on average 13kg nitrogen ha yr, compared to 20kg ha yr on the conventional system. There was only a marginal difference in yield recorded which demonstrated how legume-based cropping systems could reduce or replace the need for nitrogen fertilisers. Smith et al., (2008) studied crop diversity showing how corn grain yields were increased in a linear fashion by the amount of crops used in the rotation. Through a combination of three crops, and three cover crops they demonstrated that corn yields could be 100% higher than in continuous monocultures, comparable to the country average and without the use of agrochemical inputs. Crop diversity provides higher levels of nutrient availability, a valuable ecosystem service. However, over a 20 year period in the DOK trial yields were on average 20% less in the organic systems (Birkhofer et al., 2008).

3.4.5 Yields under a changing climate

Lotter et al., (2003) researched the effect of yields during an unusually long drought periods. Yields were higher in the organic plots by 70-90% which was concluded to be a result of the organic soils ability to retain more water. Holt Gimenez (2002) researched the differences in resistance from agroecological and conventional farms in Nicaragua after Hurricane Mitch. It was shown that agroecological farms had higher levels of top soil, more moisture in the soils, increased vegetative cover, reduced amounts of erosion and the strength of the crops prevented economic losses. Agroecological techniques were shown to reduce vulnerability and increase the sustainability of farms in developing countries (Pretty et al., 2006; Pretty et al., 2003; Altieri, 1999; Altieri, 2000).

Table 3-2 presents the findings from Pretty et al., (2006) who showed how yields were improved through agroecological farming practises in developing countries. The overall yield increase was 64%. Agroecological techniques used were: integrated pest management, integrated nutrient management, conservation tillage, agroforestry, aquaculture, water harvesting and livestock integration. Pretty et al., (2006) reported that pesticide use was shown to decline by an average of 71%, whilst yields increased by 42%. The carbon sequestration potential for agroecologically managed soil was shown to total at 11.4 Mt C y-^{1} on the projects. Thus presenting options for possible carbon trading schemes that could operationalise agroecology.

Table 3-2 Summary of the impact of agroecological techniques on small holders in developing countries. Modified from Pretty et al., (2006). Standard errors for yields are in brackets.

FAO Farming System	**No. of farmers practising**	**Hectares under agroecology**	**Average crop yield increase (%)**	**Total carbon sequestered (Mt C y-1)**
Irrigated	177,287	357,940	129.8 (+/- 21.5)	0.011
Wetland rice	8,711,236	7,007,564	22.3 (+/- 2.8)	2.53
Rainfed humid	1,704,958	1,081,071	102.2 (+/- 9.0)	0.34
Rainfed highland	401,699	725,535	107.3(+/- 14.7)	0.23
Rainfed dry/cold	604,804	737,896	99.2 (+/- 12.5)	0.20
Mixed dualistic	537,311	26,846,750	76.5 (+/- 12.6)	8.03
Coastal artisanal	220,000	160,000	62.0 (+/- 20.0)	0.032
Urban based	207,479	36,147	146.0 (+/- 32.9)	0.015
Totals	12,564,774	36,952,903	79.2 (+/- 4.5)	11.38

3.5 Discussion

The multifunctionality of sustainable agricultural practices has been demonstrated through this comparative evaluation of agroecology, which provides robust methods to internalise the negative externalities of conventional agriculture. The investigation showed that agroecological techniques had positive results in the indicators of soil fertility, biodiversity and resource efficiency. The indicators were chosen to represent the pressing concerns facing agriculture today and in the future; despite their inherent simplicity they are full of deep ramifications.

A paradigm shift from productivity to multifunctionality is expressed within the pyramid (see Figure 3-1). Yields being the goal, the pyramid demonstrating the important building blocks to get there, which aim for long-term ecological sustainability. Soil fertility is the base of the pyramid for it is the foundation of the terrestrial ecosystem and any agricultural practice that does not retain fertility in soil is unsustainable in the long-term. Biodiversity both above and below the ground is connected to soil management strategies, as the choice of inputs can foster or suppress life. Diverse farms are inherently more resilient as they enhance ecosystem services. A biodiversity strategy will fail without a sound soil fertility strategy. Resource efficiency necessitates an understanding of ecological knowledge to build a self-maintaining and self-regulating system that requires only benign inputs. Ideally inputs are generated on farm, reducing costs, fossil fuel use, and pollution. The design of agroecosystem that can incorporate high levels of nitrogen fixing trees and plants can allow a farmer to become self-sufficient in nitrogen needs. To enable such efficiency gains a strong level of collaboration amongst practitioners, researchers, scientists and government would operationalise sound agroecological management. Yields would ensue from such holistic practices, and climate change adaptability is built into the system providing long-term food security

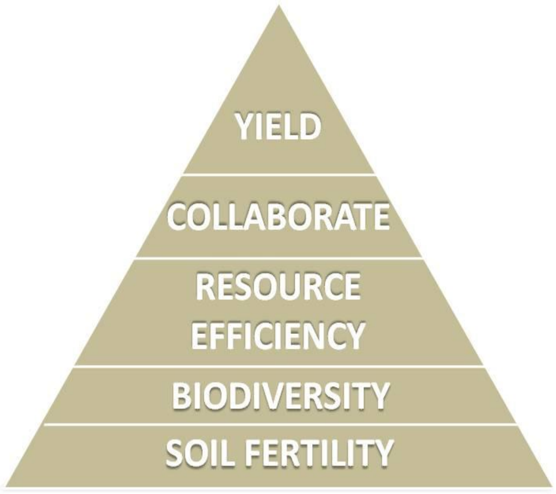

Figure 3-1 Hierarchical pyramid demonstrating the interrelated indicators of sustainable agriculture.

Managing soils for long-term fertility and productivity tackles the challenges presently facing world agriculture: to meet the food requirements of a population predicted to reach 9 billion by 2050 whilst reducing soil and ecosystem degradation, preventing continued eutrophication and water contamination and reducing emissions of GHG's. Soil degradation reduces the soil's ability to perform ecosystem services (Lal, 2007). Soil organic matter has higher levels of water retention. It binds to and helps break down pesticides and prevents nitrogen from leaching. Nutrient uptake is more efficient as a result of better structure and underground biodiversity (Kramer et al., 2006). Soil fertility management can reduce run off and can store water for longer periods of time.

To assess soil fertility on the farm scale samples are taken of specific soil quality indicators, such as microbial biomass and earthworm abundance, to gauge the initial conditions. Practices to increase the fertility would be implemented, applying organic matter, composts, manures, cover crops and green manures. Trends monitored over time demonstrate whether management decisions are increasing soil fertility. Agricultural sustainability is managed on a site specific basis; the appropriate techniques to increase soil fertility are chosen by the farmer, the manager and steward of the agroecosystem. Sustainability requires taking a long-term perspective, not just short-term problem solving. With soil fertility management a long time frame is required to generate new top soil, and to build a self-generating farm system that can control pests and nutrients internally, through biological synergisms (Altieri and Rosset, 1996).

Pest management strategies are also soil fertility management strategies (Altieri, 2002). The results showed that agroecological practices reduce the negative environmental impacts on ecosystems and increase biodiversity. Interconnectivity was clearly demonstrated as inputs of pesticides and nitrogen fertilisers decreased soil quality, correspondingly affecting a decrease in pest predators. Spiders are key predators of aphids and through the use of herbicides and fertilisers, spiders were suppressed and aphids were recorded to be twice as abundant (Birkhofer et al., 2008). Pest suppression is an ecosystem service (Zehnder et al., 2007) provided through organic soil quality management. Studies show that the ability of a plant to resist pests and disease is directly linked to optimal soil properties (Altieri and Nicholls, 2003), and therefore soil quality directly effects both above and below ground biota. Reducing vulnerability increases resilience and the sustainability of the farm system.

Synthetic chemicals were shown to reduce earthworm abundance (Reaganold et al., 1993; Mäder et al., 2006; Birkhofer, 2008), which affect soil structure and aid in the decomposing of organic matter and nutrient cycling. Chemicals also bio-accumulate in earthworms becoming toxic to animals that feed on them. The services that earthworms provide under the soil are immense, yet that service can be disrupted and stopped through chemical soil management strategies.

Long-term sustainability requires adaptive management to respond to change and to persist in the face of disturbances. If a farm is dependent on fossil fuels for the production of food without a contingency plan, then it is vulnerable to price fluctuations, as was seen with the recent oil price rises and how agrochemical inputs were affected by these higher oil costs. Lessening dependency on external inputs, through agroecological practices reduces costs and pollution emitted, and preserves fossil fuels. The results showed that energy use was decreased through the reduction of chemical inputs, with many social, economic and environmental benefits.

Agroecology can create resilience by building up long-term productivity and stability, acting as a buffer against climate variations. There are economic benefits as synthetic inputs are reduced. It is both socially acceptable and ecologically restorative (Hill, 1998; Jackson, 2002). To operationalise the transition to agroecology the idea that externalities are a side effect of progress will need to be dispelled (Dahlberg, 1994). The social and environmental costs of our food production will need to be internalised. Agroecology demonstrates a method of internalising the externalities; therefore by practising this type of agriculture practitioners are performing a public good and could be rewarded for it through subsidies (Tietenberg, 2006; Pretty, 2008). Alternatively those performing a public bad, by producing high yields whilst degrading, e.g. local water supplies through pesticide run off, should pay for their pollution. Only when the full costs are accounted for will it become more economically attractive to switch production methods (Pretty, 2000; Pretty et al., 2003; Pimentel et al., 1997).

The yields were the most difficult factor to assess in this evaluation as they varied dramatically depending on the soil conditions, crop type, farm practice, country and climatic disturbance. Results showed that yields on organic farms can compare with conventional farms, however to enable this there is more time and knowledge required to substitute for chemical inputs. There is an increase in managerial demands and new skills to be learned. Currently 99% of the worlds agricultural research funds focus on conventional, intensive farm systems. Reassessing research and development funding is a necessary stage for the transition. Multi-tiered collaborations, from agricultural communities to governing agencies, would have to co-operate to implement agroecology at a large scale.

An initial conclusion can be made that the benefits of agroecological techniques which will need to be traded off against potentially short-term lower yields in areas where conventional agricultural practice have been the norm. However, due to the positive increases in the other indicators, and the multifunctional nature of the farm there are grounds for optimism. Lower yield productivity seen after making a transition to agroecological farming after intensive conventional farming is thought to be a result of the reduced soil fertility. Intensive agriculture sees the soil as a medium to grow crops in and as such takes little concern about replenishing the organic matter and building soil fertility. It takes a substantial time commitment to develop a regenerating fertile soil.

Productivity is one goal of the multifunctional farm, however harmonisation of the lower tiers of the pyramid are needed to ensure this is goal is met. Concern that organic agriculture uses more land to grow crops, negates the fact that at present fertile land is used to grow crops for fuel, prime agricultural land is commercially developed, and intensively farmed land is being degraded at an alarming rate. Soil degradation is predominantly due to intensive agricultural practices, therefore continuation of present conventional practices presents a bleak future. Nitrogen is applied to soil to boost productivity, yet it does not increase the soil fertility, instead creating a mass imbalance throughout the ecosystem. Taking advantage of the natural nitrogen cycle through the addition of manure, compost and organic matter can increase soil fertility whilst retaining yields. This is the prime goal of sustainable agriculture and agroecology provides the techniques of how to do this.

Agroecology values traditional knowledge systems that have many solutions to the arising vulnerabilities of a changing climate. It is essential that traditional agroecosystems are recognised as examples of sophisticated applied ecological knowledge, as reservoirs of genetic diversity, otherwise the modernisation process in agriculture will continue to destroy the time-tested knowledge that they embody (Gliessman, 2007; Thrupp, 2000). Crop diversity holds options for the future of agriculture (Esquinas-Alcázar, 2005). For example there are over 300,000 different species of rice that can be grown, yet only a handful of strains are used worldwide. With a changing climate and the constant need to develop pest and disease resistant crops, a bank of diversity is the most important natural resource on earth. When species become extinct we lose options for the future, we lose the potentially unique genes that have properties to thrive in conditions of drought, or that embody particular pest resistance. It has been recently shown that the fungal infection named Ug99, a type of stem rust that afflicts wheat plants, is spreading rapidly throughout Africa and the Middle East. Starting in Kenya, moving into Ethiopia, Yemen and Iran, the disease is highlighting the vulnerability of global wheat production. Crop scientists fear Ug99 could destroy 80% of the worldwide wheat (Stokstad, 2007). With such inherent vulnerability increasing crop diversity and agrobiodiversity is a necessary insurance strategy for the future.

3.6 Conclusion

This comparative evaluation demonstrated that agroecology does create the possibility for long-term sustainability as it improves soil fertility, preserves biodiversity and reduces energy usage. These were shown to be bioindicators of sustainable agriculture. Therefore it could be concluded that Agroecology is one set of solutions for a multifunctional agriculture of the future: a practice that can help us to meet conservation and sustainability goals. ~~This is not to say that agroecology is totally sustainable yet.~~

This study demonstrated the link between agricultural practices, energy usage and subsequent emissions. There is high embedded energy in fertilisers, herbicides and pesticides; by reducing these inputs overall energy consumption is significantly reduced. Correspondingly soil quality is improved following the substitution of synthetic fertilisers with manures and legume cropping systems. A synergistic quality, documented throughout the study, is an overall improvement in biodiversity supported by the farming system, both above and below the ground.

To substitute for all synthetic inputs takes detailed knowledge of natural systems and processes. It is predominantly site specific knowledge, however can be shared. Collaboration is key to the operationalising of agroecology as knowledge of best practices needs to be transferred between agroecological practitioners. Co-operation and bottom-up research allows the generation of site specific solutions to real time problems.

There are still inputs that are required for the system to operate and there are still problems with lower yields achieved in the transition period from intensive to organic management. Many organic farms are still only at the input substitution phase, unable to benefit from the synergistic potential of a redesigned agroecosystem. Such redesign could provide permanent solutions, as productivity is sustained when resources are conserved, soil, water and ecosystems are protected.

Agroecology does play a key role in mitigating and adapting to climate change. By reducing synthetic inputs and fossil fuels agroecology reduces GHG emissions. Soil quality and biodiversity are improved, which protects ecosystems that regulate the climate and act as buffers to environmental shocks. Carbon sequestration potential is furthered as organic matter is stored in organic soils. To reduce synthetic inputs and fossil fuels requires a deep understanding of nutrient cycles, integrated pest management systems, and knowledge of how to build adaptive, dynamic cropping systems. To become sustainable it is necessary to create integrated farms that generate their own nutrients on site, thus reducing dependency on external markets. ~~Collaboration is key to the operationalising of agroecology as knowledge of best practices needs to be transferred between agroecological practitioners. Co-operation and bottom-up research allows the generation of site specific solutions to real time problems.~~

If as much research was invested in natural solutions to agricultural problems agroecological farming practices would become the conventional practice. Money is not available as it is hard to make profits by selling the idea of manure and intercropping systems. These skills are learned, where as pesticides and synthetics are products with easy profit making capabilities. As such the industrialisation of agriculture has been the cause of its unsustainability.

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APPENDICES

Guide for Authors

An International Journal for Scientific Research on the Interaction Between Agroecosystems and the Environment

Agriculture, Ecosystems & Environment publishes scientific articles dealing with the interface between agroecosystems and the natural environment, specifically how agriculture influences the environment and how changes in that environment impact agroecosystems. Preference is given to papers from experimental and observational research at the field, system or landscape level, complemented as appropriate by dynamic and statistical modelling, that bridge scientific disciplines, integrate knowledge, and are placed in an international or wide comparative context.

The focus is on the following areas:• Biological and physical characteristics of agroecosystems including land, air, and water quality.• Ecology, diversity and sustainability of agricultural systems.• Relationships between agroecosystems and the natural environment.• Agroecosystem and global environmental changes including climate change and air pollution.• Ecological consequences of intensification, soil degradation, waste application, irrigation, and mitigation options.• Environmental implications of agricultural land use and land use change.

All manuscripts are initially screened on their topic suitability and linguistic quality. The following topics are discouraged unless they provide new information regarding processes operating at the agroecosystem-environment interface: inventory and survey analysis and impact assessment, including life cycle and emergy analysis; greenhouse or laboratory-based studies; development of models or methodologies; studies that are purely agronomic, socio-economic, or political.

Preparation of manuscripts

1. Manuscripts should be written in English. Authors whose native language is not English are strongly advised to have their manuscripts checked by an English-speaking colleague prior to submission.

English language help service: Upon request, Elsevier will direct authors to an agent who can check and improve the English of their paper (before submission). Please contact authorsupport@elsevier.com for further information.

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3. Manuscripts in general should be organized in the following order:

- Title (should be clear, descriptive and not too long)
- Name(s) of author(s)
- Complete postal address(es) of affiliations
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- Present address(es) of author(s) if applicable
- Complete correspondence address to which the proofs should be sent
- Abstract
- Key words (indexing terms), normally 3-6 items
- Introduction
- Material studied, area descriptions, methods, techniques
- Results
- Discussion
- Conclusion
- Acknowledgements and any additional information concerning research grants, etc.
- References
- Tables

•Figure captions

4. In typing the manuscript, titles and subtitles should not be run within the text. They should be typed on a separate line, without indentation. Use lower-case lettertype.

Abstracts

The abstract should be clear, descriptive and not longer than 400 words.

Formulae

1. Subscripts and superscripts should be clear.
2. Give the meaning of all symbols immediately after the equation in which they are first used.
3. For simple fractions use the solidus (/) instead of a horizontal line.
4. Equations should be numbered serially at the right-hand side in parentheses. In general only equations explicitly referred to in the text need be numbered.
5. The use of fractional powers instead of root signs is recommended. Also powers of e are often more conveniently denoted by exp.
6. Levels of statistical significance which can be mentioned without further explanation are $^{*}\ P<0.05$, $^{**}\ P<0.01$ and $^{***}\ P<0.001$.
7. In chemical formulae, valence of ions should be given, as, e.g. Ca^{2+} not as Ca^{++}.
8. Isotope numbers should precede the symbols, e.g. ^{18}O.
9. The repeated writing of chemical formulae in the text is to be avoided where reasonably possible; instead, the name of the compound should be given in full. Exceptions may be made in the case of a very long name occurring very frequently or in the case of a compound being described as the end product of a gravimetric determination (e.g. phosphate as P_2O_5

Units and abbreviations

In principle SI units should be used except where they conflict with current practise or are confusing. Other equivalent units may be given in parentheses. Units and their abbreviations should be those approved by ISO (International Standard 1000:1992. SI units and recommendations for the use of their multiples and of certain other units). Abbreviate units of measure only when used with numerals.

Nomenclature

1. Authors and editors are, by general agreement, obliged to accept the rules governing biological nomenclature, as laid down in the *International Code of Botanical Nomenclature, the International Code of Nomenclature of Bacteria, and the International Code of Zoological Nomenclature,.*
2. All biotica (crops, plants, insects, birds, mammals, etc.) should be identified by their scientific names when the English term is first used, with the exception of common domestic animals.
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Tables

1. Authors should take notice of the limitations set by the size and lay-out of the journal. Large tables should be avoided. Reversing columns and rows will often reduce the dimensions of a table.
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5. Each table should have a brief and self-explanatory title.
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10. Present data with no more digits than justified by the accuracy of their measurement or simulation, and no more digits than needed for the purpose of the table. Using fewer digits usually enhances readability of tables.

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2. In the text refer to the author's name (without initial) and year of publication, followed - if necessary - by a short reference to appropriate pages. Examples: "Since Peterson (1988) has shown that..." "This is in agreement with results obtained later (Kramer,1989, pp. 12-16)".

3. If reference is made in the text to a publication written by more than two authors the name of the first author should be used followed by "et al." This indication, however, should never be used in the list of references. In this list names of first author and co-authors should be mentioned.

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Tietema, A., Riemer, L., Verstraten, J.M., van der Maas, M.P., van Wijk, A.J., van Voorthuyzen, I.,1992. Nitrogen cycling in acid forest soils subject to increased atmospheric nitrogen input. For. Ecol. Manage. 57, 29-44.

b. *For edited symposia, special issues, etc. published in a periodical*

Rice, K., 1992. Theory and conceptual issues. In: Gall, G.A.E., Staton, M. (Eds.), Integrating Conversation Biology and Agricultural Production. Agric. Ecosyst. Environ. 42, 9-26.

c. *For books*

Gaugh, Jr., H.G., 1992. Statistical Analysis of Regional Yield Trials. Elsevier, Amsterdam.

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Baker, Jr., 1993. Insects. In: De Hertogh, A., Le Nard, M. (Eds.), The Physiology of Flower Bulbs. Elsevier, Amsterdam, pp. 101-153.

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