# Low Greenhouse Gas Agriculture

## Mitigation and adaptation potential of sustainable farming systems

# LOW GREENHOUSE GAS AGRICULTURE: MITIGATION AND ADAPTATION POTENTIAL OF SUSTAINABLE FARMING SYSTEMS

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# INTRODUCTION

Each year, agriculture emits 10 to 12 percent of the global total of estimated greenhouse gas (GHG) emissions, some 5.1 to 6.1 Gt $CO_2$ equivalents per year. Smith, *et al.* (2007) and Bellarby, *et al.* (2008) have proposed mitigation options for GHG emissions that include: improved crop, grazing, livestock and manure management; conservation of organic soils; restoration of degraded lands; and the use of agro-energy crops. These mitigation options challenge farmers and policy-makers to change practices and, *inter alia*, to improve development of no-till cropping, agro-forestry and integrated crop and animal farming, and to decrease use of external inputs in food and agriculture. Organic agriculture offers techniques which are valuable for consideration in further debates.

This paper examines current farming practices and uses scientific data of mainly long- term field experiments as case studies for low greenhouse gas agriculture. It also elucidates the adaptive capacity of agro-ecological farming system approaches, using organic system case studies from the scientific literature.

# MITIGATION OPTIONS OF AGRICULTURAL PRACTICES AND TECHNIQUES

In the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Smith, *et al.* (2007) made important recommendations that illustrate the need for change in farming practices in relation to GHG issues. These are discussed below.

## Crop rotations and farming system design

Recommendations of the IPCC Fourth Assessment Report:

- improving crop varieties;
- featuring perennials in crop rotations;
- making greater use of temporary cover crops (between successive crops or between rows of plantations);
- avoiding bare fallows;
- enhancing plant and animal productivity and efficiency;
- adopting farming systems with reduced reliance on external inputs (e.g. rotations which include legume crops).

Intensive crop production - often based on monocultures and being highly productive - is also highly dependent on external inputs such as mineral fertilizers and pesticides. Sustainable agricultural practices, such as organic agriculture, strongly reduce the reliance on external inputs by:

- recycling nutrients and using nitrogen-fixing plants;
- improving cropping systems and landscapes in order to avoid synthetic pesticides and using biocontrol;
- including animals as a farm production sector and including grass clover leys for fodder production, while avoiding purchase of feed concentrates.

Nutrients for sustainable crop production are delivered by soil transformation being applied either as manure or compost or fixed by leguminous plants. Nitrogen from legumes is more sustainable in terms of ecological integrity, energy flows and food security than nitrogen (N) from industrial sources (Crews and People, 2004). These nutrients are partly biologically bound and have to be mineralized by soil biological processes. In order to avoid nutrient losses (since they are of limited availability in low-input systems), soils should be covered permanently by crops in an optimized sequence. In organic and conventional agriculture, the inclusion of cover and catch crops is both a traditional and state-of-the-art practice (Thorup-Kristensen, 2007). Bare fallows are not only unproductive, they are more prone to nutrient loss and thus, for environmental and economic reasons, should be completely avoided.

Productivity in sustainable agriculture, especially in organic agriculture, is enhanced by many indirect measures based on improving soil fertility and stimulating the roles of plants and microbes in natural soil processes. These can be based on symbiotic and asymbiotic nitrogen fixation and exploiting soil Phosphorus and water resources by symbiotic mycorrhiza (Mäder, *et al.*, 2000; 2002). The role of soil carbon is not only important for soil moisture, it contributes to counteracting greenhouse gases. In this regard, mycorrhizal fungi are practically important. Intercropping and under-sowing of legumes and integrating deep and shallow rooting crops provide another approach to increase productivity and nutrient efficiency internally. Finally, mixed farming or cooperative models between specialized farms are a basis for recycling animal faeces and diversifying production sectors, especially due to crop and fodder diversity and grass-clover leys.

The global potential of nitrogen availability through recycling and nitrogen fixation is far bigger than the current production of mineral nitrogen (Badgley, *et al.*, 2007; Niggli, *et al.*, 2007). On-farm use of farmyard manure (a practice increasingly abandoned in conventional production) needs to be reconsidered in the light of climate change. While conventional stockless arable farms become dependent on the input of synthetic nitrogen fertilizers, manure and slurry from livestock farms become an environmental problem. In these livestock operations, nutrients are available in excess and over fertilization may occur. Nutrient leaching leads to water pollution and high emissions of carbon dioxide ($CO_2$), nitrous oxide ($N_2O$) and methane ($CH_4$) are likely. Compost is particularly useful in stimulating optimized soil organic matter and at the same time reducing nutrient losses compared to either raw manure or synthetic fertilizer.

## Nutrient and manure management

Recommendations of the IPCC Fourth Assessment Report:

- improving nitrogen-use efficiency (reducing leaching and volatilization, reducing offsite $N_2O$ emissions);
- adjusting fertilizer application to crop needs (synchronization);
- using slow-release fertilizers;
- applying N when crop uptake is guaranteed;
- placing N in soil to enhance accessibility;
- avoiding any N-surplus applications;
- managing tillage and residues;
- reducing tillage or no-till.

Crop productivity in intensive agriculture has increased substantially by high inputs of soluble fertilizers and pesticides - mainly nitrogen. Under natural conditions, nitrogen is biologically bound and often limits production. Mineral nitrogen in soils may contribute to the emission of nitrous oxides and is one of the main drivers of agricultural emissions. The efficiency of fertilizer use decreases with increasing fertilization, when a great part of it is not taken up by the plant but emitted into the water bodies and the atmosphere. In summary, the emission of GHG in $CO_2$ equivalents from the production and the application of nitrogen fertilizers from fossil fuel amounts at approximately 480 million tonnes (1 percent of total global GHG emissions) in 2007. In 1960, 47 years earlier, it was less than 100 million tonnes.

Recycling nitrogen on the farm by using manure and nitrogen fixing plants (the predominant technique of organic and low external input agriculture) enhances soil quality and provides nutrients. However, timing and management of its use are essential, as soil mineralization processes should deliver the elements to the plant at times of peak demand. Excess nitrogen is prone to leaching and gaseous emission. In addition, timing and management both are site specific and, thus, challenging for farmers. As nitrogen on organic farms is far more costly than industrial nitrogen, there is an incentive to avoid losses (Stolze, *et al.*, 2000).

Certified farming systems limit the amount of fertilizer use (e.g. integrated farming) and/or livestock numbers per area or purchase of fodder (e.g. organic agriculture), thus limiting the return of nitrogen and other elements to the soil. N-application rates in organic agriculture are usually 60 to 70 percent lower than in conventional agriculture because of the recycling of organic residues and manures. In addition, the limited availability of nitrogen in organic systems requires careful, efficient management (Kramer, *et al.*, 2006). Badgley, *et al.* (2007) calculated the potential nitrogen production by leguminous plants via intercropping and off-season cropping to be 154 million tonnes, a potential which far exceeds the nitrogen production from fossil fuel and which is not fully exploited by current conventional farming techniques.

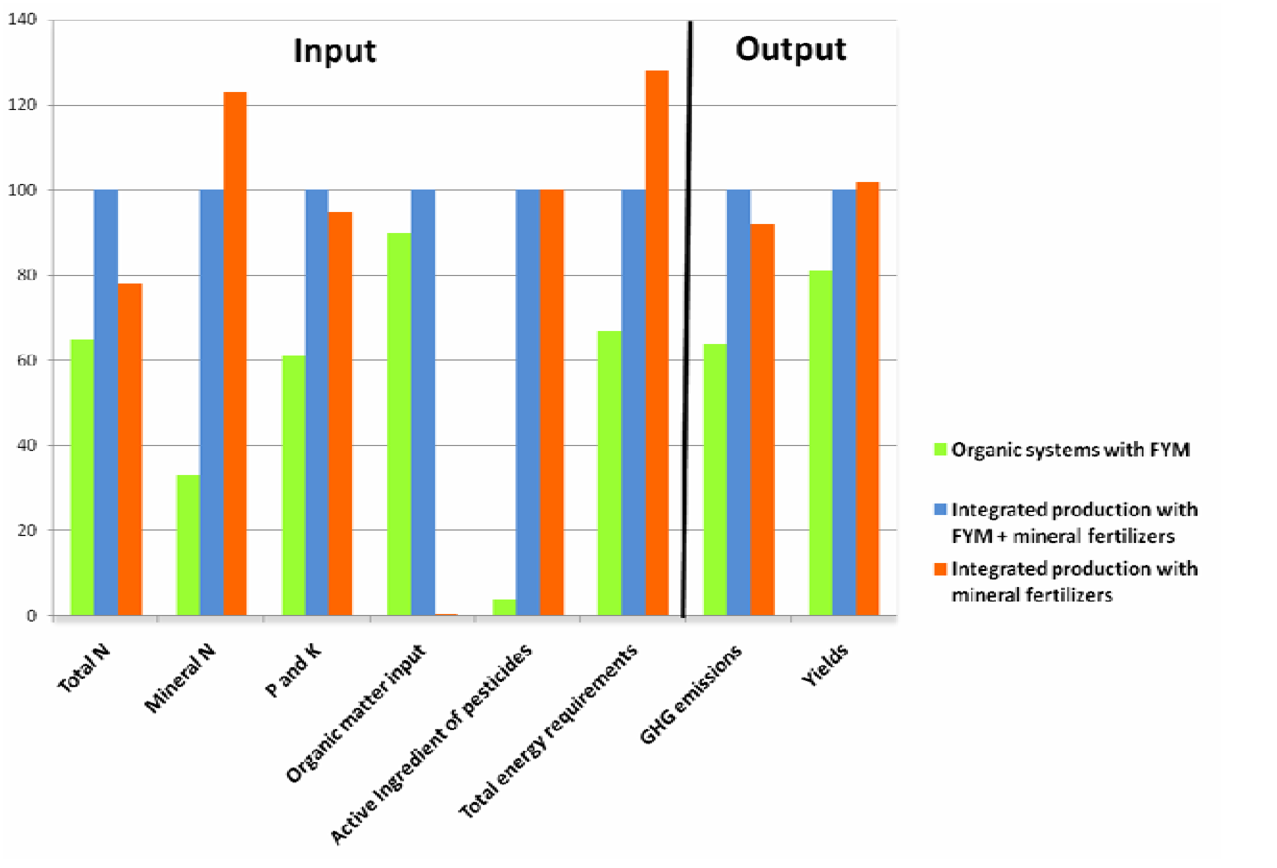


**Figure 1:** Relative input and output of three farming systems: organic agriculture; integrated production with farmyard manure; and stockless integrated production. Input of nutrients, organic matter, pesticides and energy as well as yields were calculated on the basis of 28 years. Crop sequence was potatoes, winter wheat followed by fodder intercrop, vegetables (soybean), winter wheat (maize), winter barley (grass-clover for fodder production, winter wheat), grass-clover for fodder production, grass-clover for fodder production. Crops in brackets are alterations in 1 of the 4 crop rotations (Source: DOK field experiment in Switzerland, Mäder, *et al.*, 2002)

Mäder, *et al.* (2002) report an increased efficiency of organic agriculture for most arable crops, with grain crops showing a yield reduction of only 20 percent while fertilizer inputs were lower by 50-60 percent (see figure 1). Piementel, *et al.* (2005) report yields in organic maize and soybean that are comparable to conventional maize and soybean production, indicating that depending on the environment, organic field crop production can be competitive with conventional farming even in a high-yield environment.

In life cycle assessments, Nemecek, *et al.* (2005) showed that area-based GHG emissions in the organic systems were 36 percent lower than in conventional systems. Per kg product, the GHG emissions were 18 percent lower, due to 22 percent lower dry matter yields (see Figure 1). Most of this difference is caused by $CO_2$ and $N_2O$ emissions - both of which are merely related to mineral fertilizer use in conventional farming.

In organic agriculture, the ban of mineral nitrogen and the reduced livestock units per hectare considerably reduce the concentration of easily available mineral nitrogen in soils and thus, $N_2O$ emissions. Furthermore, diversifying crop rotations with green manure improves soil structure and diminishes $N_2O$ emissions. Soils managed organically are more aerated and have significantly lower mobile nitrogen concentrations, which also reduces $N_2O$ emissions. Mathieu, *et al.* (2006) point out that higher soil carbon levels may lead to $N_2$ emission rather than $N_2O$. Petersen, *et al.* (2006) found lower emission rates for organic farming compared to conventional farming in five European countries. In a long-term study in southern Germany, Flessa, *et al.* (2002) also found reduced $N_2O$ emission rates in organic agriculture, although yield-related emissions were not reduced.

A reduction of the Global Warming Potential (GWP) has also been found on Dutch organic dairy farms and in organic peas production areas as compared to conventional (Bos, *et al.* 2006). In contrast, the authors stated higher GHG emissions for organic vegetable crops (e.g. leek and potato). Organic potatoes, tomatoes, and other various vegetables (Öko-Institut, 2007) had less GHG emissions than the compared conventional crops. In contrast, higher emissions for organic crops were modelled for the experimental farm in Scheyern (Bavaria), Germany, where organic and conventional farming systems were run on a split farm (Küstermann, *et al.* 2007). The authors also calculated the GHG emissions of 28 Bavarian commercial crop farms - organic and conventional - and found equal and, in some cases, slightly higher emissions for organic.

These figures appear controversial, but they demonstrate how crucial it is to choose the right data base, to apply the right model and to define system boundaries properly. When carbon sequestration was excluded from life cycle assessments on the Scheyern experimental farm, the GWP was 53 percent higher in the organic system compared to conventional, but was 80 percent lower when carbon sequestration was included (Küstermann, *et al.*, 2007). In a study at Michigan State University, Robertson, *et al.* (2000) calculated the net GWP for organic crops to be 64 percent lower than conventional.

## Livestock management, pasture and fodder supply improvement

Recommendations of the IPCC Fourth Assessment Report:

- reducing lifetime emissions;
- breeding dairy cattle for lifetime efficiency;
- breeding and management to increase productivity;
- implementing deep rooting species;
- introducing legumes into grasslands (to enhance productivity);
- preventing methane emissions from manure heaps and tanks;
- producing biogas;
- composting manure.

Methane accounts for about 14 percent of all greenhouse gas emissions (Barker, *et al.*, 2007). Two thirds of the methane emissions stem from enteric fermentation and manure management and, as a consequence, are directly proportional to livestock numbers.

On most organic farms, crop and livestock production are closely linked by traditional mixed farms or by regional cooperation of specialized farms or farm branches. This leads to lower input of nutrients by farmyard manure (FYM) on grassland and pastures as well as to fewer environmental problems such as run off of phosphorous, nitrogen leaching into deeper soil layers and emission of $N_2O$. Organic agriculture has an important, though not always superior, impact on the reduction of $N_20$ as livestock numbers are limited (Weiske, *et al.*, 2006; Olesen, *et al.*, 2006).

As a result of moderate fertilization, grassland and pastures tend to be more diverse on organic farms. Species reaching different soil layers in order to exploit soil nutrients better are typical for grassland on organic farms. Legumes are strongly promoted on organic grassland and pastures as they provide both nitrogen into the soil and protein into the feedstuff.

The data available on methane emissions from livestock is limited, especially with respect to the reduction of GHG emissions from ruminants and manure heaps. Some authors suggest high energy feedstuff to reduce methane emissions from ruminants (Beauchemin and McGinn, 2005), but the ruminants' unique ability to digest roughage from pastures would then not be used. Furthermore, meat and milk would be produced with arable crops (concentrates) where mineral nitrogen is an important $CO_2$ emitter, and competition to human nutrition may become a problem.

Another positive difference between organic and conventional cattle husbandry is that organic breeders aim at longevity (Kotschi and Müller-Sämann, 2004). The ratio between the unproductive phase of young cattle and the productive phase of dairy cows is favourable in organic systems because, calculated on the basis of the total lifespan of organic dairy cows, less methane is emitted. On the other hand, lower milk yields of organic cows caused by a higher proportion of roughage in the diet, might increase methane emissions per yield unit.

Storage and composting of manure and organic waste have been strongly improved on organic farms in recent years. These modern techniques (e.g. covering, processing compost and steering the compost process) prevent leaching and reduce $N_2O$ emissions. Composting manure may reduce $CH_4$ but enhance $N_2O$ emission from heaps. Compost use can greatly enhance carbon sequestration in the soil compared to raw manure use.

Biogas production from liquid slurry makes use of the evolving $CH_4$ for energy and is applied by many sustainable farmers.

## Maintaining fertile soils and restoration of degraded land

Recommendations of the IPCC Fourth Assessment Report:

- initiating revegetation;
- improving fertility by nutrient amendment;
- applying substrates such as compost and manure;
- halting soil erosion and carbon mineralization by soil conservation techniques such as reduced tillage, no tillage, contour farming, strip cropping and terracing;
- retaining crop residues as covers;
- conserving water;
- sequestering $C0_2$ into the soil as soil organic matter.

Variations of these recommendations are practiced through various techniques of organic agriculture and no-till agriculture. These include: improving soil fertility, applying substrates and retaining crop residues (organic agriculture), halting soil erosion, conserving water and sequestering $C0_2$ (organic agriculture and no-till cropping). In long-term experiments, carbon sequestration rates vary considerably (see Table 1). In the DOK field experiment in Switzerland (Mäder, *et al.*, 2002), the stockless conventional plots lost 207 kg carbon/ha/year during the first 28 years of the experiment, while the bio-dynamic plots remained stable in soil organic matter content (Fliessbach, *et al.*, 2007).

In the Rodale experiment in the USA (Pimentel, *et al.*, 2005), the manure-based organic system sequestered 1218 kg carbon per ha and year, the legume-based stockless organic system 857 kg, and the conventional system 217 kg.

Hülsbegen and Küstermann, *et al.* (2008) compared 18 organic and 10 conventional farms in Bavaria, Germany, and calculated the organic farms annual sequestration at 402 kg carbon, while the conventional farms had losses of 202 kg (see Table 1). Hepperly, *et al.* (2008) estimated that compost application and cover crops in the rotation were particularly adept at increasing soil organic matter, also compared to no tillage techniques (see Table 2).

**Table 1:** Comparison of soil carbon gains and losses in different farming systems in long term field experiments

| Field trial | Components compared | Carbon gains (+) or losses (-) kg $ha^{-1}$ $yr^{-1}$ |
|---|---|---|
| DOK experiment, CH | Organic, FYM composted | 42 |
| (Mäder, *et al.*, 2006) | Organic, FYM fresh | -123 |
| 1977 - 2005 | IP, FYM, mineral fertilizer | -84 |
| | IP, mineral fertilizer | -207 |
| SADP, USA, 1994-2002 | Organic, no till | 1 829 |
| (Teasdale, *et al.*, 2007) | Conventional, no till | 0 |
| Rodale FST, USA | Organic, FYM | 1 218 |
| (Hepperly, *et al.*, 2006; | Organic, legume based | 857 |
| Pimentel, *et al.*, 2006) | Conventional | 217 |
| Bavarian farm survey | 18 organic farms (average) | 402 |
| (Hülsbergen and | 10 conventional farms average) | -202 |
| Küstermann, 2008) | | |
| Frick reduced tillage | Organic, ploughing | 0 |
| experiment, 2002-2005 | Organic, reduced tillage | 879 |
| (Berner, *et al.*, submitted) | | |

Agriculture can help mitigate climate change by either reducing emissions of greenhouse gasses or by sequestering $CO_2$ from the atmosphere in the soil. However, the application of improved agricultural techniques (e.g. organic agriculture, conservation tillage, agroforestry) reduces or stops soil erosion and converts carbon losses into gains. Consequently, considerable amounts of $CO_2$ are removed from the atmosphere. Organic agriculture already provides effective methods to reach both of these goals, even though there is still need for further improvement.

**Table 2**: Soil carbon sequestration estimates for different agricultural practices. Data projected from Rodale long-term trials and literature values

| Practice | Soil Carbon sequestration (kg/ha) |
|---|---|
| Compost | 1 000 to 2 000 |
| Cover Crop | 800 to 1 200 |
| No-till | 100 to 500 |
| Rotation | 0 to 200 |
| Manure | 0 to 200 |
| Cover + Rotation | 900 to 1 400 |
| Comp.+Cover+ Rotation+No-till Proj. | 2 000 to 4 000 |

Considering that arable and permanent cropping systems of the world have the potential to sequester an estimated 400 kg C $ha^{-1}$ $yr^{-1}$ and pasture systems 100 - 200 kg $ha^{-1}$ $yr^{-1}$, the world's carbon sequestration may total 3.5 - 4.8 Gt $CO_2$ $yr^{-1}$. This would represent 57-78 percent of the world's agriculture GHG emissions. Lal (2004) gives lower estimates of 1.4 - 4.4 Gt $CO_2$ $yr^{-1}$, considering conservation agriculture. These carbon sequestration rates may be higher in depleted soils, but they may be restricted to the time needed for reaching a new equilibrium. So the application of sustainable management techniques that build up soil organic matter have the potential to balance a large part of the agricultural emissions, but their effect over time may be reduced as soils are built up (see Fig. 2).

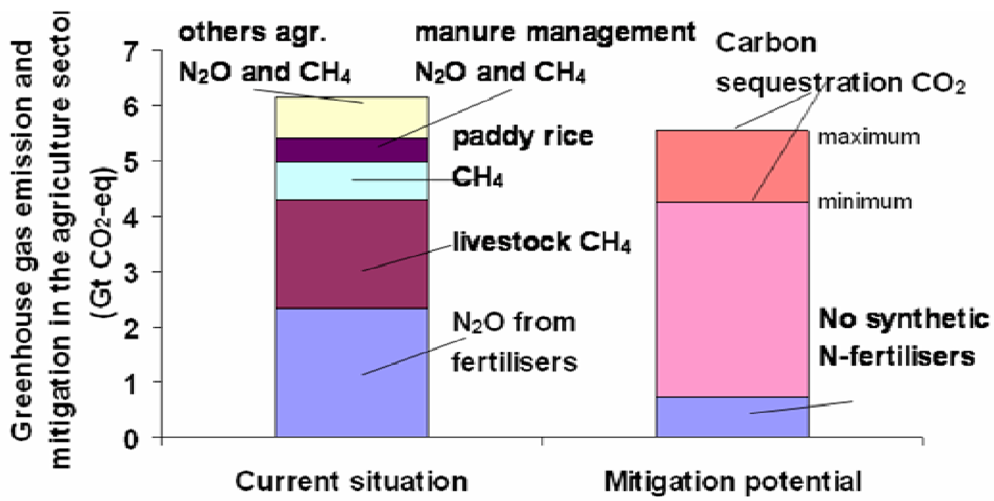


**Figure 2**: The GHG emissions of agriculture amount at approximately 6.1 Gt $C0_2$-equivalents (see current situation). With improved farm and crop management, most of these emissions could be reduced or compensated by sequestration (see mitigation potential). A conversion to organic agriculture would diminish $N_20$ emission by two third (no external mineral nitrogen input, more efficient nitrogen use). It could also enhance the sequestration of $C0_2$ into the soils in a considerable way (minimum and maximum). For this calculation, we took a sequestration rate of 400 kg C $ha^{-1}$ $yr^{-1}$ for arable and permanent crops and 100 (minimum) and 200 (maximum) kg C $ha^{-1}$ $yr^{-1}$ for pastures.

# THE POTENTIAL OF ECOLOGICALLY MANAGED FARMS TO ADAPT TO CLIMATE CHANGE

Agricultural production in most parts of the world will face less predictable weather conditions than experienced during the previous century. Weather extremes will become predominant. Resilience and adaptation are new requirements that are gaining importance for innovation in agriculture. Agriculture is not well prepared to cope with climate change, especially in Southern Africa and Asia, (Lobell, *et al.*, 2008).

## Farmer knowledge as a key to adaptation

Traditional skills and knowledge have been neglected in intensive agriculture. Organic agriculture, on the other hand, has always been based on practical farming skills, observation, personal experience and intuition. Knowledge and experience replace or reduce reliance on inputs. This practical know-how is important for manipulating complex agro-ecosystems, for breeding locally adapted seeds and livestock, and for producing on-farm fertilizers (compost, manure, green manure) and inexpensive nature-derived pesticides. Such knowledge also has been described as an adaptation "reservoir" (Tengo and Belfrages, 2004).

## Soil stability

Farming practices that preserve soil fertility and maintain, or even increase, organic matter in soils can reduce the negative effects of drought while increasing primary crop productivity. Erratic rainfalls, droughts and floods are expected to increase with rising temperatures.

Soils under organic management retain significantly more rainwater, thanks to the sponge-like properties of organic matter. These sponge properties were described for heavy loamy soils in a temperate climate in Switzerland where soil structure stability was 20-40 percent higher in organically managed soils than in conventional soils (Mäder, *et al.*, 2002). Total soil organic matter was considerably higher in organically managed soil in long-term USA field experiments than in conventional soils, and soil stability was improved (Marriott and Wander, 2006).

In the Rodale farming system trial, the amount of water percolating through the top 36 cm was 15-20 percent greater in the organic systems compared to the conventional ones. The organic soils held 816 000 litres per ha in the upper 15 cm of soil. This water reservoir was responsible for significantly higher yields of corn and soybean in dry years (Lotter, *et al.*, 2002; Pimentel, *et al.*, 2005). Under conditions where water is limited during the growing period, yields of organic farms are equal or significantly higher than those from conventional agriculture. A meta-analysis of 133 scientific papers (Badgley, *et al.*, 2007) showed that organic agriculture was particularly competitive under the lower yield environments that are common in developing countries. These findings underline that the technique inherent to organic farming of investing in soil fertility by means of green manure, leguminous intercropping, composting and recycling of livestock manure could contribute considerably to reducing greenhouse gases while also increasing global food productivity.

Water capture in organic plots was twice as high as in conventional plots during torrential rains (Lotter, *et al.*, 2003). This significantly reduced the risk of floods, an effect that could be very important if organic agriculture was practised more widely.

Observations in biodynamic systems in India suggest decreased irrigation needs of 30 to 50 percent. Better soil structure, friability, aeration and drainage, lower bulk density, higher organic matter content, soil respiration (related to soil microbial activity), more earthworms and deeper topsoil layer are all associated with the lower irrigation need (Proctor and Cole, 2002).

Experience with degraded soils of the arid tropics has shown that agricultural productivity can be enhanced using soil fertility building techniques. In Tigray Province, one of the most degraded parts of Ethiopia, agricultural productivity was doubled by soil fertility techniques such as compost application and introduction of leguminous plants into the crop sequence. By restoring soil fertility, yields were increased to a much greater extent both at farm and regional level than by using purchased mineral fertilizers (Edwards, 2007).

### Biodiversity and adaptation to climate change

Organic agriculture systems are built on a foundation of biological diversity. This diversity is based on diversity of crops, fields, rotations, landscapes and farm activities (mix of various farm enterprises). The high level of diversity of organic farms augments the ecological services that the farming system provides, as well as farm resilience (Bengtsson, *et al.*, 2005; Hole, *et al.*, 2005).

Enhanced biodiversity reduces pest outbreaks (Zehnder, *et al.*, 2007; Wyss, *et al.*, 2005; Pfiffner, *et al.*, 2003a,b). Similarly, diversified agro-ecosystems reduce the severity of plant and animal diseases, while improving utilization of soil nutrients and water (Altieri, *et al.*, 2005). The diversity of landscape and farm activities, field, crop and species is greatly enhanced in organic agriculture (Niggli, *et al.*, 2008), which makes these farms more resilient to climate change and unpredictability.

## CONCLUSIONS

Biological diversity is the keystone for ecologically based food and fiber production systems. Many components of sustainable and organic agriculture can be applied to improve all farming systems, including conventional ones. Considering the growing concern of elevated atmospheric greenhouse gases, the complex economics and availability of fossil fuels, and the deterioration of the environment and health conditions, a shift away from intense reliance on heavy chemical inputs to an intense biologically based agriculture and food system is possible today.

Sustainable and organic agriculture offer multiple opportunities to reduce greenhouse gas emissions and counteract global warming. Improving energy efficiency by better managing agricultural and food inputs can make a positive contribution to reducing agricultural greenhouse gas emissions. For example, organic agriculture reduces energy requirements for production systems by 25 to 50 percent compared to conventional chemical-based agriculture. Reducing greenhouse gases through their sequestration in soil has even greater potential to mitigate climate change. Carbon is sequestered through an increase of the beneficial soil organic matter content. Improving soil sequestration of greenhouse gases is desirable in both low- and high-yield crop and animal systems. However, soil improvement is particularly important for agriculture in developing countries where crop inputs such as chemical fertilizers and pesticides are not readily available, their costs are prohibitive, they require equipment, and knowledge for their proper application is not widespread.

In order to reduce trade-offs among food security, climate change and ecosystem degradation, productive and ecologically sustainable agriculture with strongly reduced greenhouse gas emissions is crucial. In that context, organic agriculture represents a multi-targeted and multifunctional strategy; it offers an interesting concept that is being implemented quite successfully by a growing number of pioneer farms and food chains.

Many components of organic agriculture can be implemented within other sustainable farming systems, and organic agriculture might be a starting point for an ecological intensification of food production. The system-oriented and participative concept of organic agriculture, combined with sustainable cutting-edge technology, might offer greatly needed solutions in the face of climate change.

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