LOW GREENHOUSE GAS AGRICULTURE

MITIGATION AND ADAPTATION POTENTIAL OF SUSTAINABLE FARMING SYSTEMS

Niggli, U., Fließbach, A., Hepperly, P. and Scialabba, N. 2009. Low Greenhouse Gas Agriculture: Mitigation and Adaptation Potential of Sustainable Farming Systems. FAO, April 2009, Rev. 2 – 2009.

Research Institute of Organic Agriculture (FiBL): www.fibl.org
The Rodale Institute, USA: www.rodaleinstitute.org
FAO, Natural Resources Management and Environment Department: www.fao.org/organicag

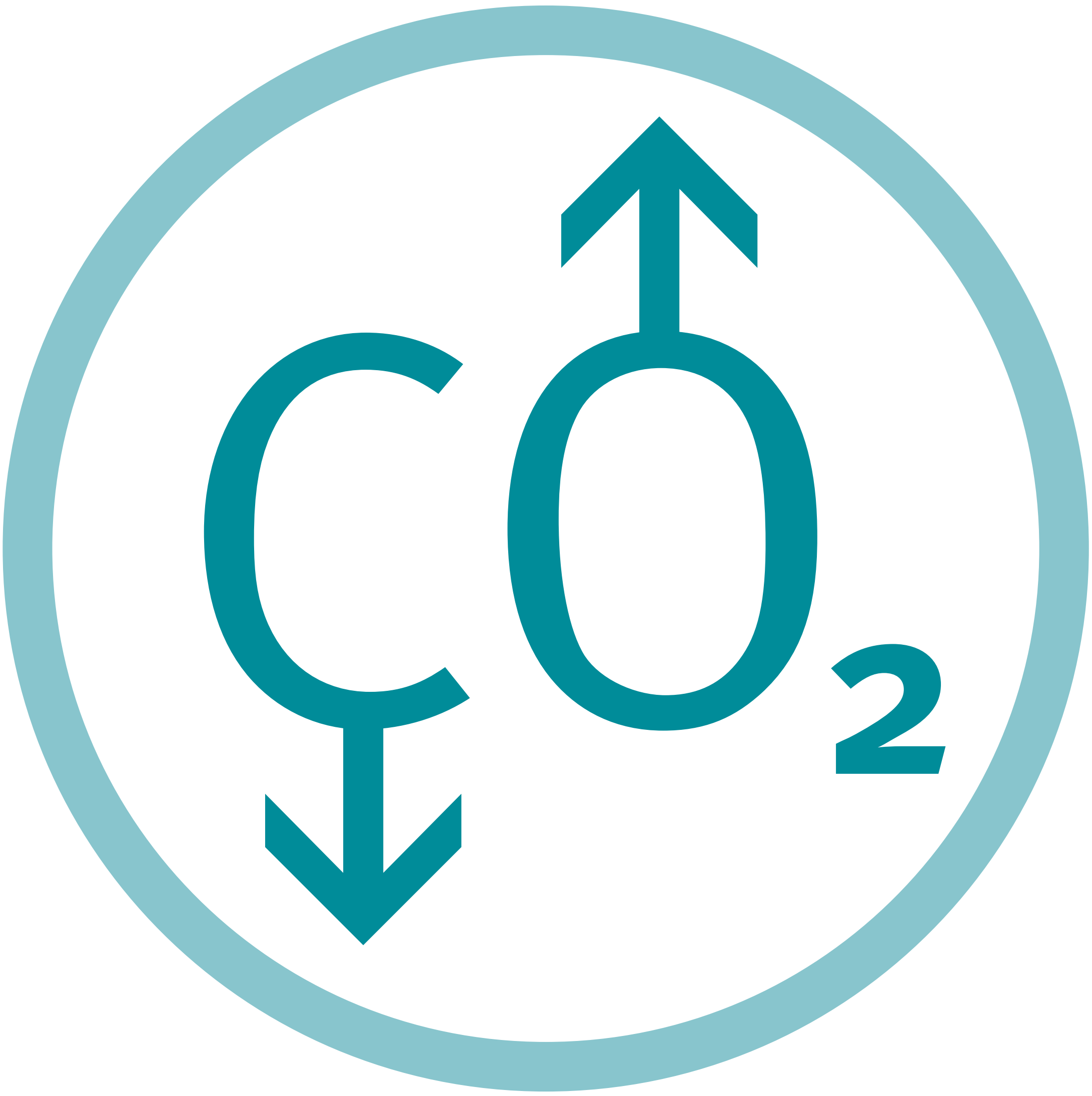
This document was first published in May 2008, on the occasion of the High-Level Conference on World Food Security: The Challenges of Climate Change and Bioenergy, Rome, 3-5 June 2008. This revised version is issued in April 2009.

LOW GREENHOUSE GAS AGRICULTURE

MITIGATION AND ADAPTATION POTENTIAL OF SUSTAINABLE FARMING SYSTEMS

CONTENTS

List of tables and figures


CO_2

INTRODUCTION

Is low greenhouse gas emission (GHG) agriculture possible? Is it, in fact, desirable? In seeking answers to these two basic but extremely relevant questions, this study examines current farming practices, and incorporates scientific databases from long-term field experiments as case studies for low GHG agriculture. Further, the study examines the changes that will be needed for low greenhouse gas agriculture systems to become a reality. It also elucidates the adaptive capacity of agro-ecological farming system approaches, using organic system case studies from the scientific literature.

Each year, agriculture emits 10 to 12 percent of the total estimated 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, finding that both farmers and policy-makers will face challenges from the GHG-related changes needed in agriculture. Areas for improvement include increased use of no-till cropping, agro-forestry, and integrated crop and animal farming, and decreased use of external inputs in food and agriculture. The techniques offered by organic agriculture are valuable for consideration in these efforts.

MITIGATION OPTIONS OF AGRICULTURAL PRACTICES AND TECHNIQUES

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) made important recommendations on how agriculture could mitigate GHG emissions (Smith, *et al.*, 2007).

This report summarizes these recommendations (in the four sections below) and then compares them to scientific data from organic agriculture in order to assess the mitigation potential of organic farming. The four major recommendations include: **crop rotations and farming system design; nutrient and manure management; livestock management; pasture and fodder supply improvement; fertile soil maintenance and restoration of degraded land.**

Crop rotations and farming system design

IPCC Fourth Assessment Report recommended:

- improve crop varieties,
- feature perennials in crop rotations,
- use cover crops (between successive crops or between rows of plantations) and avoid bare fallows,
- enhance plant and animal productivity and efficiency,
- adopt farming systems with reduced reliance on external inputs (e.g. rotations which include legume crops).

Two of organic agricultures current priorities – improving crop and animal productivity under low-external-input environments and selecting varieties and breeds especially fit for these conditions – can cope with several of the above-mentioned recommendations simultaneously. NUE-CROPS, a new EU Framework Programme for Research and Technological Development (FP7) project, addresses crop breeding with the goal of identifying nutrient- efficient varieties of wheat, potatoes, maize, and oilseed rape. It also will study the combined effects of genotype and management practices on nutrient use efficiency, with a special emphasis on reduced tillage organic farming. Most recent genetic studies on maize and wheat have shown that selecting under organic and low-external-input agriculture can improve yields and yield stability considerably (Burger, *et al.*, 2008; Löschenberger, *et al.*, 2008). Another EU project, LowInputBreed, began in spring 2009 with aims of better exploiting effects of interactions of genotype and environment on genetic gain in breeding programs in organic and low input livestock systems.

Intensive crop production (often based on monocultures and high productivity) depends greatly 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 wastes as nutrient source,
- using nitrogen-fixing plants,
- improving cropping systems and landscapes,
- avoiding synthetic pesticides,
- integrating crops and animals into a single farm production sector and including grass clover leys for fodder production, while avoiding purchase of feed concentrates.

In order to avoid nutrient losses, especially since nutrients are limited in low-input systems, soils should be covered permanently by crops in an optimized sequence. In organic agriculture, the inclusion of cover and catch crops is both a traditional and state-of-the-art practice (Thorup-Kristensen, *et al.,* 2003). Bare fallows are not only unproductive, they are more prone to nutrient loss. As purchased organic fertilizers are expensive, organic farmers have not only environmental reasons to avoid losses, but also economic incentives.

Nutrients for sustainable crop production can be delivered by soil transformation through application of manure or compost or fixed by leguminous plants. Nitrogen (N) from legumes is more sustainable in terms of ecological integrity, energy flows and food security than nitrogen from industrial sources (Crews and Peoples, 2004). These nutrients are partly biologically bound and have to be mineralized by soil microbiological processes.

Productivity in sustainable agriculture is enhanced by many indirect measures based on improving soil fertility and stimulating the roles of plants and microbes in natural soil processes. The role of soil carbon is pre-eminent. It is important for soil moisture while also contributing to counteracting greenhouse gases. Such soil processes driven productivity gains are typical for organic farming:

Mycorrhizal fungi are practically important in carbon sequestration and mineral solubilization. Intercropping and under-sowing legumes as well as combining deep and shallow rooting crops provide other approaches to increase productivity and nutrient efficiency internally through nitrogen resource management. Needed nitrogen can be supplied using both symbiotic and non-symbiotic nitrogen fixation and exploiting soil phosphorus and water resources by symbiotic mycorrhiza (Mäder, *et al.*, 2000; 2002). Integrated crop and animal farming and cooperation 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.

Nutrient and manure management

IPCC Fourth Assessment Report recommended:

- improve nitrogen-use efficiency (reducing leaching and volatilization, reducing offsite N_2O emissions),
- adjust fertilizer application to crop needs (synchronization),
- use slow-release fertilizers,
- apply N when crop uptake is guaranteed,
- place N into soil to enhance accessibility,
- avoid any surplus-N applications,
- manage tillage and residues conservatively,
- reduce unnecessary tillage using minimum and no-till strategies.

In agro-ecosystems, mineral nitrogen in soils is the driver of crop productivity in many cases. Crop productivity has increased substantially through utilization of heavy inputs of soluble fertilizers – mainly nitrogen – and synthetic pesticides. However, only 17 percent of the 100 Mt N produced in 2005 was taken up by crops. The remainder was somehow lost to the environment (Erisman, *et al.*, 2008). Between 1960 and 2000, the efficiency of nitrogen use for cereal production decreased from 80 to 30 percent (Erisman, *et al.*, 2008)

High levels of reactive nitrogen (NH_4, NO_3) in soils may contribute to the emission of nitrous oxides and are main drivers of agricultural emissions. The efficiency of fertilizer use decreases with increasing fertilization, because a great part of the fertilizer is not taken up by the plant but instead emitted into the water bodies and the atmosphere. In summary, the emission of GHG in CO_2 equivalents from the production and application of nitrogen fertilizers from fossil fuel amounted to 750 to 1080 million tonnes (1 to 2 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 enhances soil quality and provides nutrients. This is the predominant technique of organic and low external input agriculture. However, timing and management of its use are essential. Soil mineralization processes should deliver the elements to the plant at times of peak demand. Organic and green manures as well as nitrogen from legumes can be managed very precisely due to the design of the crop rotations including cover and catch crops (Thorup-Kristensen, *et al.*, 2003). In addition, improved distribution systems, such as slurry injections into soils or drag hoses, reduce nutrients losses considerably. All these techniques might be knowledge-intensive for farmers and require site specific adaptations. As nitrogen on organic farms is far more costly than industrial nitrogen, there is a strong incentive to avoid losses and to learn and implement recycling techniques (Stolze, *et al.*, 2000).

The global potential of nitrogen availability through recycling and nitrogen fixation is far bigger than the current production of synthetic nitrogen, as shown Table 1. 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. The concept of either mixed farms or close cooperation between crop and livestock operations – a common practice of most forms of sustainable farming, especially organic ones – can contribute considerably to mitigation and adaptation. In addition, different forms of compost, especially composted manure, are particularly useful in stimulating soil microbial processes and in building up stable forms of the soil organic matter (Fließbach and Mäder, 2000).

Table 1

Global nitrogen input and nitrogen circuits in agriculture

Nitrogen derived from industrial production (by the Haber-Bosch process with fossil fuel combustion)	90 to 100 Mt N per year	Erisman, *et al.*, 2008, IFA, 2009
Potential nitrogen production by leguminous plants via intercropping and off-season cropping (without competing cash crops). This potential is not used by conventional farmers.	140 Mt N per year	Badgley, *et al.*, 2007
Nitrogen from livestock faeces of 18.3 billion farm animals (FAO, global figure). In specialized farming structure with strong segregation between crop and livestock production, nitrogen from manure and slurry is inefficiently used.	160 Mt N per year	Estimated by the authors

Farming systems with ecological objectives either limit the amount of fertilizer use (such as in integrated farming) and/or limit livestock numbers per area or the purchase of fodder (such as in 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), as shown in Table 2.

Table 2

Input and output of organic and integrated farming systems of the DOK trial

DOK LONG-TERM FIELD TRIAL IN THERWIL SWITZERLAND (DATA FOR THE YEARS 1977 TO 2005)				
Parameter	Unit	Organic farming	Integrated farming (IP) with FYM	Organic in % of IP
Nutrient input	kg N_{total} ha^{-1} yr^{-1}	101	157	64
	kg N_{min} ha^{-1} yr^{-1}	34	112	30
	kg P ha^{-1} yr^{-1}	25	40	62
Pesticides applied	kg K ha^{-1} yr^{-1}	162	254	64
	kg ha^{-1} yr^{-1}	1.5	42	4
Fuel use	L ha^{-1} yr^{-1}	808	924	87
Total yield output for 28 years	%	83	100	83
Soil microbial biomass „output"	tons ha^{-1}	40	24	167

(*source*: Mäder, *et al.*, 2006)

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.

Pimentel, *et al.* (2005) report yields in organic maize and soybean are comparable to conventional maize and soybean production. Depending on the environment, this indicates that organic field crop production can be competitive with conventional farming even in a high-yield environment.

Mäder, *et al.* (2002) report an increased efficiency of input use of organic agriculture,, with crop yield reduction of less than 20 percent while fertilizer inputs were lower by 50 to 60 percent (Table 2).

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 (Table 2). Most of this difference was caused by CO_2 and N_2O emissions – both of which are mainly related to mineral fertilizer use in conventional farming.

Benchmarking: GHG emissions per land area or per product quantity?

Environmental concern – such as nitrate losses into groundwater or biodiversity loss through over-fertilization and overgrazing – is the main rationale behind organic agriculture standards on stocking density, limiting livestock to two units per ha in most productive areas. Animal welfare is another reason, because lower stocking densities offer free movement to animals. Therefore, the very purpose of the organic paradigm is producing less livestock while increasing the share of crops for human consumption. In this respect, per area benchmarking of GHG emissions is more appropriate than per product quantity for farming system comparisons, especially in the context of climate change and livestock production.

In organic agriculture, the ban of mineral nitrogen and the reduced livestock units per ha considerably decrease 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 further reduces N_2O emissions. Mathieu, *et al.* (2006) pointed 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 pea production areas as compared to conventional (Bos, *et al.* 2006). In contrast, the authors found higher GHG emissions for organic vegetable crops (e.g. leek and potato). In other studies, organic potatoes, tomatoes, and various other vegetables (Öko-Institut, 2007) had less GHG emissions than the compared conventional crops. In contrast, higher emissions for organic crops were found in the experimental farm in Scheyern (Bavaria), Germany (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.

Table 3

Above ground net primary production and relative Global Warming Potential

	Net primary production [kg ha^{-1} yr^{-1}]	C-sequestration [kg CO_2-eq ha^{-1} yr^{-1}]	Net global warming potential [kg CO_2-eq ha^{-1} yr^{-1}]		Net global warming potential per NPP [kg CO_2-eq ton^{-1}]	
Conventional tillage	9240	0	1140	100%	123.38	100%
No till	9190	1100	140	12%	15.23	12%
Low input with legume cover	8840	400	630	55%	71.27	58%
Organic with legume cover	7790	290	410	36%	52.63	43%

(*source*: Robertson *et al.*, 2000)

These figures 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 Michigan State University study, Robertson, *et al.* (2000) calculated that net GWP for organic systems was 64 percent lower than conventional systems (Table 3). Due to 16 percent lower net primary productivity, the GWP on a product basis was 57 percent lower in organic than in conventional.

Reduced tillage techniques, increasingly and successfully applied to organic systems (Berner, *et al.*, 2008; Teasdale, *et al.*, 2007), enhance carbon sequestration rates considerably (see Table 4). Contrary to conventional no-till systems, organic reduced tillage systems do not increase herbicide and synthetic nitrogen input.

Livestock management, pasture and fodder supply improvement

IPCC Fourth Assessment Report recommended:

- reduce lifetime emissions,
- breed dairy cattle for lifetime efficiency,
- breed and manage to increase productivity,
- plant deep-rooting species in primary production,
- introduce legumes into grasslands (to enhance productivity),
- prevent methane emissions from manure heaps and tanks,
- utilize biogas as a resource,
- compost 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 to 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 phosphorous run-off, 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_2O, because organic has limited livestock numbers (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. Typically on organic farms, the diverse grassland species reach different soil layers in order to improve exploitation of soil nutrients. Legumes are strongly promoted on organic grasslands and pastures, as they increase nitrogen uptake into the soil and provide 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 recommend 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 feed concentrates produced in remote arable lands, which make intensive use of mineral nitrogen (an important CO_2 emitter), and which use crops for feed rather than for food, with the attendant human nutrition implications.

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. Using the modern techniques, such as covering, processing compost and steering the compost process, prevents leaching and reduces 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. Finally, 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 restoring degraded land

IPPC Fourth Assessment Report recommended:

- re-vegetate,
- improve fertility by nutrient amendment,
- apply substrates such as compost and manure,
- halt soil erosion and carbon mineralization by soil conservation techniques such as reduced tillage, no tillage, contour farming, strip cropping and terracing,
- retain crop residues as covers,
- conserve water,
- sequester CO_2 by increasing soil organic matter content.

Organic agriculture and no-till agriculture already practice these recommendations. Techniques for improving soil fertility, applying substrates and retaining crop residues, halting soil erosion, conserving water and sequestering CO_2 are found in both organic and conventional agriculture. In long-term experiments, carbon sequestration rates vary considerably (see Table 2).

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 Farming Systems Trial in the mid-Atlantic region of the continental USA, the manure-based organic system sequestered 1 218 kg carbon per ha and year, the legume-based stockless organic system sequestered 857 kg, and the conventional system sequestered 217 kg (Pimentel, *et al.*, 2005).

Küstermann, *et al.* (2008) compared 18 organic and 10 conventional farms in Bavaria, Germany and, using the REPRO model, calculated the organic farms' annual sequestration at 402 kg carbon, while the conventional farms had losses of 202 kg. Hepperly, *et al.* (2008) estimated that compost application and cover crops in the rotation were particularly adept at increasing soil organic matter, also when compared to no tillage techniques (see Table 4).

Agriculture can help mitigate climate change by either reducing GHG emissions or by sequestering CO_2 from the atmosphere in the soil. 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, especially with regards reduced tillage techniques.

Table 4

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 C HA^{-1} YR^{-1}	RELATIVE YIELDS OF THE RESPECTIVE CROP ROTATIONS
DOK[1] Experiment, Research Institute FiBL and Federal Research Institute Agroscope (Switzerland) (Mäder, et al., 2002, Fliessbach, et al., 2007)) Running since 1977	Organic, with composted farm yard manure	+ 42	83 %
	Organic, with fresh farm yard manure	- 123	84 %
	Integrated Production, with fresh farm yard manure and mineral fertilizer	- 84	100 %
	Integrated Production, stockless, with mineral fertilizer	- 207	99 %
SADP, USDA-ARS, Beltsville, Maryland (USA) (Teasdale, et al., 2007) Running 1994 to 2002	Organic, reduced tillage	+ 810 to + 1738	83 %
	Conventional, no tillage	0	100 %
Rodale FST, Rodale Institute, Kurtztown, Pennsylvania (USA,) (Hepperly, et al., 2006; Pimentel, et al., 2005) Running since 1981	Organic, with farm yard manure	+ 1218	97 %
	Organic, with legume based green manure.	+ 857	92 %
	Conventional	+ 217	100 %
Frick[2] Reduced Tillage Trial, Research Institute FiBL, (Switzerland) (Berner, et al., 2008) Running since 2002	Organic, with ploughing	0	100 %
	Organic, with reduced tillage	+ 879	112 %
Scheyern[3] Experimental Farm, University of Munich, Germany (Rühling, et al. 2005), Running since 1990	Organic	+ 180	57 %
	Conventional	- 120	100 %

[1] In the DOK trial, all plots started with exactly the same soil organic matter content. In the organic treatment where the farm yard manure was applied as compost, the SOM slightly increased whereas in the organic and integrated systems with fresh manure, the SOM slightly decreased. The integrated treatment with mineral fertilizers (stockless) showed a significant annual carbon loss.
[2] In the Frick trial, only organic treatments are compared (ploughing versus reduced tillage). No conventional treatment is part of the comparison.
[3] In Scheyern, the experimental farm is separated into two parts, a conventional and an organic one. The organic rotation is situated on poorer soils which explains the bigger differences in yields.

IS A LOW GREENHOUSE GAS EMISSION AGRICULTURE POSSIBLE?

The global GHG emissions of agriculture amount at 5.1 to 6.1 Gt CO_2-equivalents (see Figure 1, top graph). Considering that arable and permanent cropping systems of the world have the potential to sequester an estimated 200 kg C ha^{-1} yr^{-1} and pasture systems 100 kg ha^{-1} yr^{-1}, the world's carbon sequestration may total 2.4 Gt CO_2-eq. yr^{-1}. This minimum scenario for a conversion to organic farming would mitigate 40 percent of the world's agriculture GHG emissions. Lal (2004) gives similar estimates of 1.4 - 4.4 Gt CO_2-eq. yr^{-1}, considering conservation agriculture. When combining organic farming with reduced tillage techniques, the sequestration rates on arable land could be easily increased to 500 kg C ha^{-1} yr^{-1}. This maximum organic scenario would mitigate 4 Gt CO_2-eq. yr^{-1} or 65 % of the agricultural GHG. These carbon sequestration rates may be higher in depleted soils, but they may be restricted to the time needed for reaching a new equilibrium. This indicates that the application of sustainable management techniques that build up soil organic matter have the potential to balance a large part of the agricultural emissions, although their effect over time may be reduced as soils are built up. Long-term comparison field trials in temperate climate zones have shown no slowing of sequestration for more than 30 years. Modelling of sequestration potentials of a conversion from conventional to organic agriculture in Scandinavia gives a time span of 50 to 100 years (Foereid and Høgh-Jensen, 2004).

By a conversion to organic farming, another approximately 20 percent of the agricultural GHG could be reduced by abandoning industrially produced nitrogen fertilizers (Figure 1, bottom graph), as is practiced by organic farms. This is an encouraging figure, showing that low GHG agriculture might be possible and farming could be climate neutral.

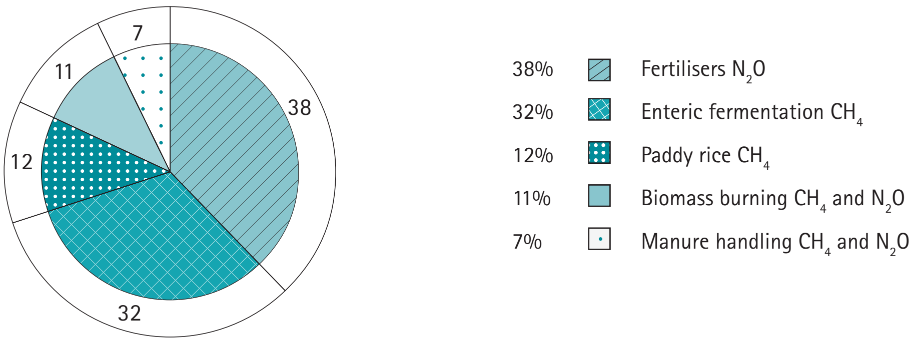
Eventually, a 100 percent conversion to organic agriculture could decrease global yields. According to various studies, this yield reduction could be 30 to 40 percent in intensively farmed regions under the best geo-climate conditions. In less favourable regions, yield losses tend to zero. In the context of subsistence agriculture and in regions with periodic disruptions of water supply brought on by droughts or floods, organic agriculture is competitive to conventional agriculture and often superior with respect to yields. Numerous case studies show that in comparison to traditional subsistence farming, organic yields were 112 percent higher due to crop rotation, legumes and closed circuits. Data on the competitiveness and performance of organic agriculture can be found in Badgley, *et al.*, 2007; Halberg, *et al.* 2006; Sanders, 2007; UNEP-UNCTAD Capacity-building Task Force on Trade, Environment and Development, 2008.

Organic agriculture has huge potential, both in terms of the recommendations of the IPCC Fourth Assessment Report and for future food security. This potential should be considered in further climate change mitigation strategies in agricultural production.

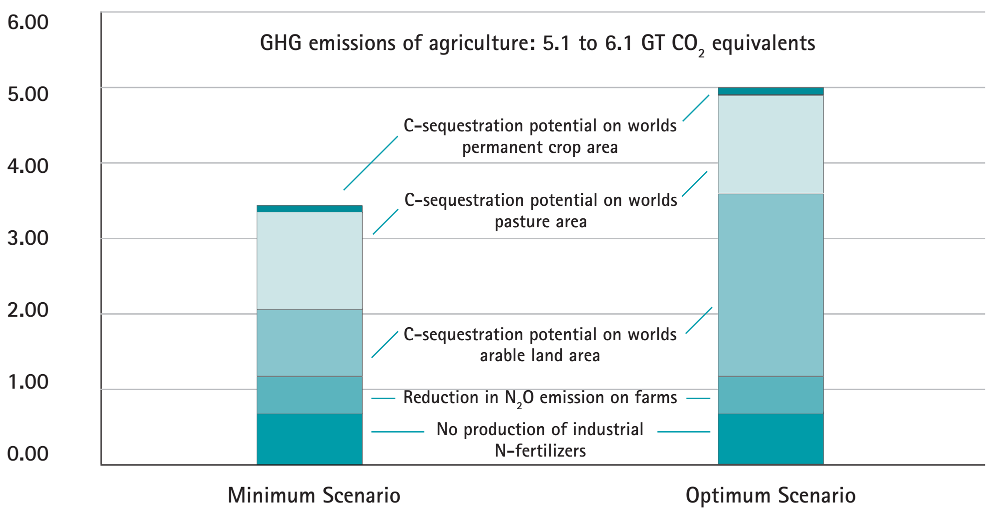
- Organic agriculture reduces erosion caused by wind and water as well as by overgrazing at a rate of 10 million ha annually (Pimentel, 1995) – a crucial precondition for future food security.
- Organic agriculture is a good way to rehabilitate poor soils, restore organic matter content and bring such soils back into productivity.
- Organic agriculture is inherently based on lower livestock densities and can compensate for lower yields by a more effective vegetable production. Organic has a land use ratio of 1:7 for vegetable and animal production.
- The potential productivity of organic farms and organically managed landscapes can be improved considerably by scientific agro-ecological research.
- Organic agriculture offers many added benefits such as conserving agricultural biodiversity, reducing environmental degradation impacts and integrates farmers into high value food chains (for a comprehensive literature study see Niggli, *et al.*, 2008).

Figure 1
Agricultural emissionons and mitigation potential

GHG emissions of the agricultural sector (Smith *et al.*, 2007)



GHG reduction and mitigation potentials



The GHG emissions of agriculture amount at 5.1 - 6.1 Gt CO_2-equivalents. With improved farm and crop management, most of these emissions could be reduced or compensated by sequestration. A conversion to organic agriculture would reduce industrial N-fertilizer use that emits 6.7 kg CO_2-eq per kg N on manufacture and another 1.6 percent of the applied N as soil N_2O emission. It could also enhance the sequestration of CO_2 into the soils in a considerable way. For the minimum scenario, we took a sequestration rate of 200 kg C ha^{-1} yr^{-1} for arable and permanent crops and 100 kg C ha^{-1} yr^{-1} for pastures. The maximum scenario combines organic farming with reduced tillage on arable land (sequestration rate 500 kg C ha^{-1} yr^{-1}).

THE POTENTIAL OF ECOLOGICALLY MANAGED FARMS TO ADAPT TO CLIMATE CHANGE

As a result of climate change, agricultural production in most parts of the world not only faces less predictable weather conditions than in previous centuries, weather extremes will become predominant. Agriculture is not well prepared to cope with climate change, especially in Southern Africa and Asia (Lobell, *et al.*, 2008).

This means that our food systems must focus on building resilience as well as the ability to adapt to a warming climate. As these attributes become more appreciated, they also will lead to greater innovation in agriculture and food sectors.

Farmer knowledge as a key to adaptation

Intensive agriculture has neglected traditional skills and knowledge. Organic agriculture, on the other hand, always has been based on practical farming skills, observation, personal experience and intuition – traditional systems that function without reliance on modern inputs. This practical adaptation "reservoir" of knowledge (Tengö and Belfrage, 2004) 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.

Improving Soil

Farming practices that conserve and improve soil fertility are important for the future of agriculture and food production. Erratic rainfalls, droughts and floods are expected to increase with rising temperatures. Soil organic matter can help mitigate or avoid their negative effects while increasing primary crop productivity.

Soils under organic management retain significantly more rainwater, thanks to the sponge-like properties of organic matter. For example, due to the sponge properties in heavy loamy soils in a temperate climate in Switzerland, soil structure stability was 20 to 40 percent higher in organically managed soils than in conventional soils (Mäder, *et al.*, 2002). In different long-term field experiments in the USA, organic matter was considerably higher in organically managed soil than in conventional soils, and soil stability was improved (Marriott and Wander, 2006). In addition, higher organic matter content and more biomass in soils make organic fields less prone to soil erosion (Reganold, *et al.*, 1987; Siegrist, et al., 1998)

In the Rodale Farming System Trial, the amount of water percolating through the top 36 cm of soil was 15 to 20 percent greater in the organic systems than in the conventional ones. The organic soils held 816 000 litres per ha in the top 15 cm of soil. This water reservoir was responsible for significantly higher yields of corn and soybean in dry years (Lotter, *et al.*, 2003; Pimentel, *et al.*, 2005). Under conditions in which water is limited during the growing period, yields of organic farms are equal or significantly higher than those of 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 were practised more widely.

Observations of biodynamic systems in India found 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 a deeper topsoil layer are all associated with the lower irrigation need (Proctor and Cole, 2002).

Experience with degraded soils in 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 at both farm and regional level than by using purchased mineral fertilizers (Edwards, 2007).

Biodiversity and adaptation to climate change

The diversity of landscapes, farming activities, fields, and agrobiodiversity is greatly enhanced in organic agriculture (Niggli, *et al.*, 2008), which makes these farms more resilient to unpredictable weather patterns that results from climate change. (Bengtsson, *et al.*, 2005; Hole, *et al.*, 2005).

Organic agriculture systems build on a foundation of conserving and improving diversity by using diverse crops, rotations and mixed farm strategies. Enhanced biodiversity reduces pest outbreaks (Zehnder, *et al.*, 2007; Wyss, *et al.*, 1995; 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).

CONCLUSIONS

Considering the growing concern of elevated atmospheric GHGs, 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.

Biological diversity is the keystone of ecologically based systems for the production of food and fibre. Many components of organic agriculture can be applied to improve all farming systems, including conventional ones.

Sustainable and organic agriculture offer multiple opportunities to reduce GHGs and counteract global warming. For example, organic agriculture reduces energy requirements for production systems by 25 to 50 percent compared to conventional chemical-based agriculture. Reducing GHGs through their sequestration in soil has even greater potential to mitigate climate change. Carbon is sequestered through an increase of soil organic matter content. Improving soil sequestration of carbon 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 special equipment, and the knowledge needed 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 is crucial. In that context, organic agriculture represents a multi-targeted and multifunctional strategy. It offers a proven alternative concept that is being implemented quite successfully by a growing number of farms and food chains. Currently, 1.2 million farmers practise organic agriculture on 32.2 million ha of land (Willer and Kilcher, 2009).

Many of organic agriculture's components can be implemented within other sustainable farming systems. The system-oriented and participative concept of organic agriculture, combined with new sustainable technologies (such as no tillage), offer greatly needed solutions in the face of climate change.

REFERENCES

Altieri, M. A., Ponti, L. and Nicholls, C. (2005): Enhanced pest management through soil health: toward a belowground habitat management strategy. *Biodynamics* (Summer) pp. 33-40.

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M.J., Avilés-Vàzquez, K., Samulon, A., Perfecto, I. (2007): Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems* **22**, 86-108.

Barker T., I. Bashmakov, L. Bernstein, J. E. Bogner, P. R. Bosch, R. Dave, O. R. Davidson, B. S. Fisher, S. Gupta, K. Halsnæs, G.J. Heij, S. Kahn Ribeiro, S. Kobayashi, M. D. Levine, D. L. Martino, O. Masera, B. Metz, L. A. Meyer, G.-J. Nabuurs, A. Najam, N. Nakicenovic, H. -H. Rogner, J. Roy, J. Sathaye, R. Schock, P. Shukla, R. E. H. Sims, P. Smith, D. A. Tirpak, D. Urge-Vorsatz, D. Zhou (2007): Technical Summary. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available at www.mnp.nl/ipcc/pages_media/FAR4docs/final_pdfs_ar4/TS.pdf

Beauchemin, K.A., McGinn, S.M. (2005): Methane emissions from feedlot cattle fed barley or corn diets. *Journal of Animal Science* **83**, 653-661.

Bellarby, J., Foereid, B., Hastings, A., Smith, P. (2008): *Cool Farming: Climate impacts of agriculture and mitigation potential*, Greenpeace International, Amsterdam (NL). 44 p.

Bengtsson, J., Ahnström, J. and Weibull, A.-C. (2005): The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *Journal of Applied Ecology*, **42**, 261-269.

Berner, A., Hildermann, I., Fließbach, A., Pfiffner, L., Niggli, U., Mäder, P. (2008): Crop yield and soil fertility response to reduced tillage under organic management. *Soil & Tillage Research* **101**, 89-96.

Bos, J.F.F.P.; de Haan, J.J.; Sukkel, W. and Schils, R.L.M. (2007): Comparing energy use and greenhouse gas emissions in organic and conventional farming systems in the Netherlands. Paper presented at the 3rd QLIF Congress: Improving Sustainability in Organic and Low Input Food Production Systems, University of Hohenheim, Germany, March 20-23, 2007.

Burger, H., Schloen, M., Schmidt, W., Geiger, H.H. (2008) Quantitative genetic studies on breeding maize for adaptation to organic farming. *Euphytica* **163**: 501-510

Burger, H., Schloen, M., Schmidt, W., Geiger, H.H. (2008) Quantitative genetic studies on breeding maize for adaptation to organic farming. Euphytica 163: 501-510

Crews, T. E. and Peoples, M. B. (2004) Legume versus fertilizer sources of nitrogen: ecological tradeoffs and human needs. *Agriculture, Ecosystems & Environment* **102**, 279-297.

Edwards, S. (2007): The impact of compost use on crop yields in Tigray, Ethiopia. Institute for Sustainable Development (ISD). *Proceedings of the International Conference on Organic Agriculture and Food Security*. FAO, Rom. Obtainable at: ftp://ftp.fao.org/paia/organicag/ofs/02-Edwards.pdf

Erisman, J.W., Sutton, M.A., Galloway, J., Klimont, Z., Winiwarter, W. (2008): How a century of ammonia synthesis changed the world. *Nature Geoscience* **1**, 636-639.

Flessa, H., Ruser, R., Dörsch, P., Kamp, T., Jimenez, M.A., Munch, J.C., Beese, F. (2002): Integrated evaluation of greenhouse gas emissions (CO_2, CH_4, N_2O) from two farming systems in southern Germany. *Agriculture, Ecosystems and Environment* **91**, 175-189.

Fließbach, A., and Mäder, P. (2000): Microbial biomass and size-density factions differ between soils of organic and conventional agricultural systems. *Soil Biology & Biochemistry* **32**, 757-768.

Fließbach, A., Oberholzer, H.-R., Gunst, L., Mäder, P. (2007): Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. *Agriculture, Ecosystems & Environment* **118**, 273-284.

Foereid , B. and Høgh-Jensen, H. (2004): Carbon sequestration potential of organic agriculture in northern Europe – a modelling approach. *Nutrient Cycling in Agroecosystems* **68,** No. 1, p. 13-24

Halberg; Niels Timothy B. Sulser ; Henning Høgh Jensen ; Mark W. Rosegrant ; Marie Trydeman Knudsen (2006) The impact of organic farming on food security in a regional and global perspective. CABI Publishing.

Hepperly, P., Douds Jr., D., Seidel, R. (2006): The Rodale faming systems trial 1981 to 2005: long term analysis of organic and conventional maize and soybean cropping systems. In: *Long-term field experiments in organic farming.* Raupp, J., Pekrun, C., Oltmanns, M., Köpke, U. (eds.). pp 15-32. International Society of Organic Agriculture Resarch (ISOFAR), Bonn.

Hepperly, P., Moyer, J., Pimentel, D., Douds Jr, D., Nichols, K. And Seidel, R. (2008) Organic Maize/Soybean Cropping Systems Significantly Sequester Carbon and Reduce Energy Use. In: Neuhoff, D. *et al.*:(Eds): Cultivating the Future Based on Science. Volume 2 - Livestock, Socio-economy and Cross disciplinary Research in Organic Agriculture. Proceedings of the Second Scientific Conference of the International Society of Organic Agriculture Research (ISOFAR), held at the 16th IFOAM Organic World Congress in Cooperation with the International Federation of Organic Agriculture Movements (IFOAM) and the Consorzio ModenaBio, 18 – 20 June 2008 in Modena, Italy.

Hole, D.G., A.J. Perkins, J.D. Wilson, I.H. Alexander, P.V. Grice and A.D. Evans (2005): Does organic farming benefit biodiversity? *Biological Conservation*, **122**, 113-130.

Hülsbergen, K.-J., Küstermann, B. (2008): Optimierung der Kohlenstoffkreisläufe in Ökobetrieben. *Ökologie und Landbau* **145**, 20-22.

IFA, 2009: http://www.fertilizer.org/

Kotschi J and Müller-Sämann K (2004): *The Role of Organic Agriculture in Mitigating Climate Change – a Scoping Study*. IFOAM. Bonn, 64 p.

Kotschi, J. (2006). Coping with Climate Change, and the Role of Agrobiodiversity. Conference on International Agricultural Research for Development. Tropentag 2006 University of Bonn. October 11-13, 2006.

Kramer, S.B., Reganold, J.P., Glover, J.D., Bohannan, B.J.M., Mooney, H.A. (2006): Reduced nitrate leaching and enhanced denitrifier activity and efficiency in organically fertilized soils. *Proceedings of the National Academy of Sciences of the USA* **103**, 4522-4527.

Küstermann, B., Kainz, M., Hülsbergen, K.-J. (2008): Modeling carbon cycles and estimation of greenhouse gas emissions from organic and conventional farming systems. *Renewable Agriculture and Food Systems* **23**, 38-52.

Küstermann, B., Wenske, K. and Hülsbergen, K.-J. (2007): Modellierung betrieblicher C- und N-Flüsse als Grundlage einer Emissionsinventur [Modelling carbon and nitrogen fluxes for a farm based emissions inventory]. Paper presented at Zwischen Tradition und Globalisierung - 9. Wissenschaftstagung Ökologischer Landbau, Universität Hohenheim, Stuttgart, Deutschland, 20-23.03.2007. Archived at http://orgprints.org/9654/

Lal, R. (2004): Soil carbon sequestration impacts on global climate change and food security. *Science* **304**, 1623-1627.

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P. and Naylon, R. L. (2008): Prioritizing Climate Change Adaptation. Needs for Food Security in 2030. *Science* **319**: 607 – 610.

Löschenberger, F., Fleck, A., Grausgruber, H., Hetzendorfe, H., Hof, G., Lafferty, J., Marn, M., Neumayer, A., Pfaffinger, G., Birschitzky, J. (2008) Breeding for organic agriculture: the example for winter wheat in Austria. *Euphytica* **163**: 469-480

Löschenberger, F., Fleck, A., Grausgruber, H., Hetzendorfe, H., Hof, G., Lafferty, J., Marn, M., Neumayer, A., Pfaffinger, G., Birschitzky, J. (2008) Breeding for organic agriculture: the example for winter wheat in Austria. Euphytica 163: 469-480

Lotter, D., Seidel, R. & Liebhardt, W. (2003): The Performance of Organic and Conventional Cropping Systems in an Extreme Climate Year. *American Journal of Alternative Agriculture* **18**: 146-154.

Mäder, P., Edenhofer, S., Boller, T., Wiemken, A., Niggli, U. (2000): Arbuscular mycorrhizae in a long-term field trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation. *Biology and Fertility of Soils* **31**, 150-156.

Mäder, P., Fließbach, A., Dubois, D., Gunst, L., Fried, P., Niggli, U. (2002): Soil Fertility and Biodiversity in Organic Farming. *Science* **296**, 1694-1697.

Mäder, P., Fließbach, A., Dubois, D., Gunst, L., Jossi, W., Widmer, F., Oberson, A., Frossard, E., Oehl, F., Wiemken, A., Gattinger, A., Niggli, U. (2006): The DOK experiment (Switzerland). In: *Long-term field experiments in organic farming*. Raupp, J., Pekrun, C., Oltmanns, M., Köpke, U. (eds.). pp 41-58. Koester, Bonn.

Marriott, E.E., Wander, M.M. (2006): Total and labile soil organic matter in organic and conventional farming systems. *Soil Science Society of America Journal* **70**, 950-959.

Mathieu, O., Lévêque, J., Hénault, C., Milloux, M.-J., Bizouard, F., Andreux, F. (2006): Emissions and spatial variability of N_2O, N_2 and nitrous oxide mole fraction at the field scale, revealed with 15N isotopic techniques. *Soil Biology & Biochemistry* **38**, 941-951.

Nemecek, T., Huguenin-Elie, O., Dubois, D., Gaillard, G. (2005): Ökobilanzierung von Anbausystemen im Schweizerischen Acker- und Futterbau. *Schriftenreihe der FAL* **58**. FAL Reckenholz, Zürich.

Niggli, U., Fließbach, A., Schmid, H. and Kasterine, A. (2007): Organic farming and climate change. International Trade Centre UNCTAD/WTO, Geneva, 27 pages.

Niggli, U., Hepperly, P., Fließbach, A., and Mäder, P. (2008) Does Organic Farming have Greater Potential to Adapt to Climate Change? In: Neuhoff, D. *et al.*:(Eds): Cultivating the Future Based on Science. Volume 2 - Livestock, Socio-economy and Cross disciplinary Research in Organic Agriculture. Proceedings of the Second Scientific Conference of the International Society of Organic Agriculture Research (ISOFAR), held at the 16th IFOAM

Organic World Congress in Cooperation with the International Federation of Organic Agriculture Movements (IFOAM) and the Consorzio ModenaBio, 18 – 20 June 2008 in Modena, Italy, 586-589.

Niggli, U., Slabe, A., Schmid., O, Halberg, N. And Schlueter, M. (2008) Vision for an Organic Food and Farming Research Agenda to 2025. Organic Knowledge for the Future. http://www.tporganics.eu/upload/TPOrganics_VisionResearchAgenda.pdf, 44 pages.

Öko-Institut (2007): Arbeitspapier: Treibhausgasemissionen durch Erzeugung und Verarbeitung von Lebensmitteln. Authors: Fritsche U. and Eberle U. Öko-Institut Darmstadt. Download at the Öko-Institut Homepage at http://www.oeko.de/oekodoc/328/2007-011-de.

Olesen, J.E., Schelde, K., Weiske, A., Weisbjerg, M.R., Asman, W.A.H., Djurhuus, J., (2006): Modelling greenhouse gas emissions from European conventional and organic dairy farms. *Agriculture, Ecosystems & Environment* **112**: 207-222.

Petersen, S.O., Regina, K., Pöllinger, A., Rigler, E., Valli, L., Yamulki, S., Esala, M., Fabbri, C., Syväsalo, E., Vinther, F.P. (2005): Nitrous oxide emissions from organic and conventional crop rotations in five European countries. *Agriculture, Ecosystems & Environment* **112**, 200-206.

Pfiffner, L. und Luka, H. (2003a): Effects of low-input farming systems on carabids and epigeal spiders - a paired farm approach. *Basic and Applied Ecology* **4**: 117-127.

Pfiffner, L.; Merkelbach, L. & Luka, H. (2003b): Do sown wildflower strips enhance the parasitism of lepidopteran pests in cabbage crops? *International Organisation for Biological and Integrated Control of Noxious Animals and Plants/West Palaearctic Regional Section Bulletin* **26**: 111-116.

Pimentel, D., Hepperly, P., Hanson, J., Douds, D., Seidel, R. (2005): Environmental, energetic, and economic comparisons of organic and conventional farming systems. *Bioscience* **55**, 573-582.

Pimentel, D.; Harvey, C.; Resosudarmo, P.; Sinclair, K.; Kurz, D.; McNair, M.; Crist, S.; Shpritz, L.; Fitton, L.; Saffouri; R. & Blair; R. (1995). Environmental and Economic Costs of Soil Erosion and Conservation Benefits. *Science*, **267**, 1117-1123.

Proctor P. and Cole G. (2002) Grasp the Nettle: Making Biodynamic Farming and Gardening Work. Random House Publishing, New Zealand.

Reganold, J.P.; Elliot, L.F. and Unger, Y.L. (1987). Long-term effects of organic and conventional farming on soil erosion. *Nature* **330**, 370-372.

Robertson, G.P., Paul, E.A., Harwood, R.R. (2000): Greenhouse gases in intensive agriculture: contributions of individual gases to the radiative forcing of the atmosphere. *Science* **289,** 1922-1925.

Rühling, I., Ruser, R., Kölbl, A., Priesack, E., Gutser, R. (2005): Kohlenstoff und Stickstoff in Agrarökosystemen. In: Landwirtschaft und Umwelt - ein Spannungsfeld. Osinski, E., Meyer-Aurich, A., Huber, B., Rühling, v., Gerl, G., Schröder, P. (eds.). pp 99-154. Ökom Verlag, München.

Sanders, J. (2007) Economic impact of agricultural liberalisation policies on organic farming in Switzerland. PhD thesis, Aberystwyth University.

Siegrist, S., Staub, D., Pfiffner, L. and Mäder, P. (1998) Does organic agriculture reduce soil erodibility? The results of a long-term field study on loess in Switzerland. Agriculture, Ecosystems and Environment 69, 253-264.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko (2007): Agriculture. In Climate Change (2007): Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available at http://www.mnp.nl/ipcc/pages_media/FAR4docs/final_pdfs_ar4/Chapter08.pdf

Soil Association (2008) Nitrogen Fertiliser and Climate Change. 5pp

Stolze, M., Piorr, A., Haring, A., Dabbert, S. (2000) The Environmental Impacts of Organic Farming in Europe – Organic Farming in Europe: Economics and Policy, vol. 6. University of Hohenheim, Stuttgart.

Teasdale, J.R., C.B. Coffmann and Ruth W. Magnum (2007): Potential Long-Term Benefits of No-Tillage and Organic Cropping Systems for Grain Production and Soil Improvement. *Agronomy Journal*: **99**, 1297-1305.

Tengö, M. and Belfrage, K. (2004): Local management practices for dealing with change and uncertainty: a cross-scale comparison of cases in Sweden and Tanzania. *Ecology and Society*, **9**. online: www.ecologyandsociety.org/vol9/iss3/art4.

Thorup-Kristensen, K., Magid, J. and Jensen, L.S. (2003) Catch crops and green manures as biological tools in nitrogen management in temperate zones. *Advances in Agronomy* **79**, 227-302.

UNEP-UNCTAD Capacity-building Task Force on Trade, Environment and Development (2008) Organic Agriculture and Food Security in Africa. http://www.unep-unctad.org/cbtf/publications/UNCTAD_DITC_TED_2007_15.pdf

Weiske, A., Vabitsch, A., Olesen, J.E., Schelde, K., Michel, J., Friedrich, R., Kaltschmitt, M., (2006): Mitigation of greenhouse gas emission in European conventional and organic dairy farming. *Agriculture, Ecosystems and Environment* **112**, 221-232.

Willler, H. and Kilcher, L. (Eds.) (2009) The World of Organic Agriculture. Statistics and Emerging Trends 2009. IFOAM, DE-Bonn and FiBL, CH-Frick.

Wyss, E, Niggli, U and Nentwig, W (1995) The impact of spiders on aphid populations in a strip-managed apple orchard. J. Appl. Ent. 119, 473-478.

Zehnder, G., Gurr, G.M., Kühne, S., Wade, M.R., Wratten, S.D. and Wyss, E. (2007) Arthropod pest management in organic crops. Annual Review of Entomology, 52, 57-80.