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Chapter-8

Eco-Safety and Agricultural Sustainability through Organic Agriculture

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SUMMARY

Conventional agriculture has been contributing significantly to several modern day environmental problems like global climate change, soil degradation, water pollution, biodiversity loss etc. directly or indirectly. Organic agriculture has been identified as one of the eco-friendly agriculture techniques and is being promoted worldwide to meet the increasing demand for organic products and conserve the natural eco-systems. It helps mitigating climate change through reduced emission of green house gases (GHGs), greater C sequestration and less use of fossil fuel. Besides, it has been found helpful to reduce export of harmful agro-chemicals to water bodies, biodiversity conservation, restoring soil health etc. Organic agriculture can help to meet the objectives of sustainable and eco-friendly agriculture.

Introduction

Conventional agriculture is one of the foremost factors responsible for ecological degradation all over the world. Besides, degrading other resources like land, water, forest, biodiversity, it has been responsible to contribute to global climate change through emission of GHGs like CO_2, CH_4 and N_2O. This underlines the need to develop agriculture management practices that take care of resource conservation thus ensuring sustainability of agriculture. This is particularly important in the scenario of challenging task to feed the burgeoning population and almost no chance of enhancing the extra land under cultivation. Agriculture not only contributes to global climate change but also is victim of it. Therefore agriculture needs to contribute its share of climate change mitigation through adopting eco-friendly production techniques like organic farming. During the last two decades, there has been a significant sensitization of the global community towards environmental conservation and assurance of quality food. Ardent promoters of organic farming consider that it can meet both the demands. After almost a century of neglect, organic agriculture is now finding place in the mainstream of development and shows great promise commercially, socially and environmentally. While there is continuum of thought from earlier days to the present, the modern organic movement is radically different from its original form. It now has environmental sustainability and productivity at its core, in addition to the founders concerns for healthy soil, healthy food and healthy people.

Organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, cultural, biological, and mechanical methods, as opposed to using synthetic materials to fulfill any specific function within the system. An organic production system is designed to a) enhance biological diversity within the whole system; b) increase soil biological activity; c) maintain long-term soil fertility; d) recycle wastes of plant and animal origin in order to return nutrients to the land, thus minimizing the use of non-renewable resources; e) rely on renewable resources in locally organized agricultural systems; f) promote the healthy use of soil, water and air as well as minimize all forms of pollution that may result from agricultural practices (Codex Alimentarius,1999).According to International Federation of Organic Agriculture Movement (IFOAM) organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved. Organic agriculture dramatically reduces external inputs by controlling pests and diseases naturally, with both traditional and modern methods, increasing both agricultural yields and crop resistance to pest and diseases and exploiting organic nutrient sources. Keeping this hypothesis in view this chapter has been prepared to focus on the environmental benefits of organic agriculture to promote it as an important environment conservation strategy.

Ecological problems due to conventional agriculture

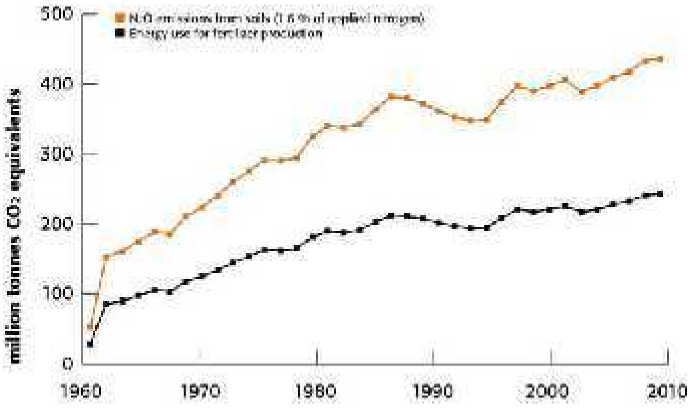
Direct impacts of conventional agriculture on the environment arise from farming activities which contribute to soil erosion, land salination, biodiversity loss due to habitat loss and harmful agrochemicals and release of greenhouse gases. The spread of green revolution in the Indo Gangetic Plains has been accompanied by over exploitation of land and water resources, and use of fertilizers and pesticides have increased many fold. Shifting cultivation has also been an important cause of land degradation. Leaching from extensive use of pesticides and fertilizers is an important source of contamination of water bodies. Intensive agriculture and irrigation contribute to land degradation particularly salination, alkalization and water logging. Therefore, conventional agriculture has been found unsustainable on long term basis due to various ecological consequences associated with it.

Emission of green house gases from agricultural activities

Modern industrial agriculture of the "Green Revolution" era contributes a great deal to climate change by contributing to emission of GHGs directly or indirectly. It is the main source of nitrous oxide and methane gases released into the atmosphere; besides contributing significant amount of CO_2 due to large scale use of fossil fuels and loss of soil carbon to the atmosphere especially through deforestation to make more land available for crops and plantations. Our planet's soils contain one thousand six hundred billion tonnes of carbon, more than twice as much as is contained in the atmosphere. Much of this will be released in the coming decades; unless there is a rapid switch to sustainable, largely organic, agricultural practices.

According to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), greenhouse gas emissions from the agricultural sector account for 10–12% or 5.1–6.1 Gt of the total anthropogenic annual emissions of CO_2-equivalents (IPCC, 2007 a). The total emissions were 6.1Gt CO2e, made up almost entirely of CH_4 (3.3 Gt) and N_2O (2.8Gt). However, this accounting includes only direct agricultural emissions; emissions during the production of agricultural inputs such as nitrogen fertilizers, synthetic pesticides and fossil fuels used for agricultural machinery and irrigation are not calculated. Agriculture production practices emit at least one-third of global anthropogenic GHG emissions, if forest land conversion to agriculture, food handling and processing activities are accounted (Scialabba and Mu¨ller-Lindenlauf 2010). Currently it is responsible for 25% of the world's carbon dioxide emissions, 60% of methane gas emissions and 80% of nitrous oxide; all powerful greenhouse gases (Bunyard, 1996). Nitrous oxide is generated through the action of denitrifying bacteria in the soil when land is converted to agriculture. When tropical rainforests are converted into a pasture, nitrous oxide emissions increase by three times. All in all, land conversion is leading to the release of around half a million tonnes a year of nitrogen in the form of nitrous oxide (Simon et al. 2007). Nitrogenous fertilisers are another major source of nitrous oxide emissions. N_2O is emitted during both the production of nitrogenous fertilizers (Figure.1) as well as after their application in the field. With continuous increase in fertilizer applications, especially in developing countries, nitrous oxide emissions from agriculture could double over the next 30 years (Bunyard, 1996). In the Netherlands, which has the world's most intensive farming, as much as 580 kilograms per hectare of nitrogen in the form of nitrates or ammonium salts are applied every year as fertiliser, and at least 10% of that nitrogen goes straight back into the atmosphere, either as ammonia or nitrous oxide (Moser et al.1991).

The growth of agriculture is also leading to increasing emissions of methane. In the last few decades, there has been a substantial increase in livestock numbers, cattle in particular which has resulted into conversion of tropical forests to pasture. Cattle emit large amounts of methane and the destruction of forests to raise cattle contributes to increased emissions of CO_2. Worldwide, the emissions of methane by livestock amount to some 70 million tonnes (Goldsmith, 2010). Even the fertilisation of grasslands with nitrogen fertilisers can both decrease methane uptake by soil bacteria and increase nitrous oxide production, thereby increasing atmospheric concentrations of both these gases. The expansion of rice paddies has also seriously increased methane emissions which accounts for 11% of the global agricultural GHGs emissions.



[**Figure 1 :** Energy used for production of synthetic fertilizers and emissions of nitrous oxide (N_2O) from soils after application of fertilizer (in million tons CO_2 equivalent), based on data from the International Fertilizer Industry Association IFA (Source: http://www.fertilizer.org/)]

In the United States, agriculture contributes 7.4 percent of the national greenhouse gas emissions (Anon 2007b). Livestock enteric fermentation and manure management account for 21 percent and 8 percent, respectively of the national methane emissions. Agricultural soil management, such as fertilizer application and other cropping practices, accounts for 78 percent of the nitrous oxide emitted in the USA (Anon 2007c). In the UK, agriculture is estimated to contribute directly 7.4 percent to the nation's greenhouse gas emissions, with fertilizer manufacture contributing a further 1 percent (Moser et al. 1991) and is comprised entirely of methane at 37.5 percent of national total and nitrous oxide at around 95 percent of the national total (Anon 2007a). Enteric fermentation is responsible for 86 percent of the methane contribution from agriculture, the rest from manure; while nitrous oxide emissions are dominated by synthetic fertilizer application (28 percent) and leaching of fertilizer nitrogen and applied animal manures to ground and surface water (27 percent). Figure 2 shows sectorwise contribution to GHG emission from agriculture in world. In India agriculture accounts for 28 % of total GHG emission and is second only to energy production and transformation (Table 1).

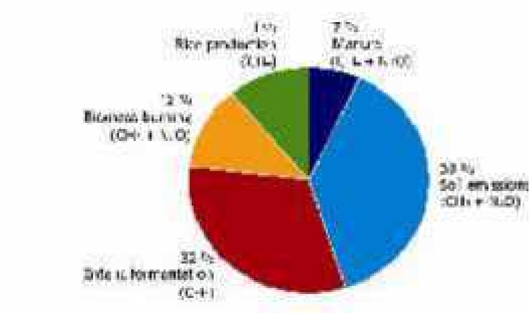


Figure 2 : Main sources of greenhouse gas emissions in the agricultural sector in 2005 *(Source : Smith et al. 2007).*

Table 1 : Contribution to GHG emissions by sectors in India

Sector	**Percent**
Energy production & transformation	35
Agriculture	28
Industry including	20
Industrial combustion	12
Other industrial processes	8
Transport	8
Residential sector	5
Land Use, Land use change and Forestry	2
Others (including waste)	1

(Source : NATCOM, MoEF, 2004)

Among the immediate options available organic agriculture must be considered seriously until suitable substitutions to fossil fuel based activities are developed. The energy used for the chemical synthesis of nitrogen fertilizers, which are totally excluded in organic systems, represent up to 0.4–0.6 Gt CO_2 emissions (FAOSTAT 2009; EFMA 2005). This is as much as 10% of direct global agricultural emissions and around 1% of total anthropogenic GHG emissions. Williams et al. calculated the total primary energy burden of conventional wheat production in the UK to be allocated by 56% to mineral fertilizers and by 11% to pesticides (FAOSTAT, 2009). Pimentel calculated similar results for corn in USA and allotted 30–40% energy burden for fertilization and 9–11% for plant protection for wheat and corn (Williams et al. 2006).

Pollution of water bodies

In recent years many reports have identified agricultural non-point source pollution as the leading cause of water quality deterioration in rivers and lakes. The global mean N use efficiency is estimated to be about 50% (Mosier, 2002). The efficiency of fertilizer use in India is only 30-35 percent and the part of balance 65 -70 percent may reach the water bodies. The remaining quantity of nitrogen is lost into the environment and part of this can possibly end up in water bodies. The current public health standards for safe drinking water require that maximum contaminant level (MCL) should not exceed nitrate concentrations of 10 ppm as nitrate-N or 45 ppm as nitrate (10 ppm nitrate-N is the same as 45 ppm nitrate). Nitrates in drinking water are associated with a number of health problems. Recurrent acute respiratory tract infections in some areas of Rajasthan have been attributed to high nitrate concentrations in drinking water (Gupta et al. 2000).Nitrate contamination of ground water depends upon climate, fertilizer or manure management, soil, crop, and farming systems. Eutrophication leading to suffocation of aquatic plants and animals due to rapid growth of algae, referred to as "algae blooms", is literally killing lakes, rivers and other bodies of water. Similarly heavy metals present in the fertilizers and sewage sludge leach into ground water.

Loss of biodiversity

Agriculture has been responsible for wildlife habitat degradation worldwide. There has been a 500% expansion in the extent of crop and pasturelands worldwide in the last 300 years. Habitat loss is now identified as the main threat to 85 - 90% of all species described by IUCN as ‘threatened’ or ‘endangered’ and is the most commonly recorded reason for species extinction during the last 20 years (Anon d). Growing high-yielding, uniform cultivars has been responsible for reducing the number of genetically viable species used in agriculture; 75% of agricultural crop diversity (agrobiodiversity) has been lost in the last 100 years (FAO 1998). Native animal breeds are also declining; it has been estimated that every week at least one breed of domestic animal becomes extinct, and over 25% of listed breeds are at risk (Anon D.). The contamination of cultivated and wild species by invasive exotic genes introduced through genetically modified organisms (GMOs) is causing pollution of the natural gene pool (Anon 2007d). Almost all pesticides are toxic in nature and pollute the environment leading to grave damage to ecology as well as animal health. Their indiscriminate use leaves toxic residues in food grains, fodder, vegetables, meat, milk, milk products etc. besides in soil and water. High doses of pesticide residues in water bodies lead to mass killing of aquatic life. The application of weedicides may lead to killing of non-target plants which reduces the biodiversity. The contamination of cultivated and wild species by invasive exotic genes introduced through genetically modified organisms (GMOs) is causing pollution of the natural gene pool. Similarly chemical fertilizers are also source of heavy metals which cause deleterious effects on animal health (Table 2) and with regular application of fertilizers the concentration of heavy metals increase to harmful levels. Deb and Joshi (Deb and Joshi, 1994) have also reported about presence of heavy metals in the chemical fertilizers and sludge.

Table 2 : Concentration of selected heavy metals in commonly used fertilizers (ppm on dry weight basis)

S. No.	**Source**	**Arsenic**	**Cadmium**	**Lead**	**Nickel**
1.	Urea	<0.04	<0.2	<0.4	<0.2
2.	DAP	9.9-16.2	4.6-35.5	2.1-3.7	7.4-222
3.	MOP	0.4	<0.2	<0.4-10	<0.2
4.	TSP	10.3	15.0	11	17

(Source : Chhonkar *2003)*

Besides, pesticide use in conventional agriculture is responsible for harmful effects on human health. According to WHO, 14000 people die every year in the third world countries due to pesticide poisoning. Pesticides are becoming less effective against target pests due to their indiscriminate use. Five hundred species of insect-pests have already developed genetic resistance to pesticides, as have 150 plant disease pathogens, 133 kinds of weeds and 70 species of fungus (Bunyard 1996). The reaction today is to apply evermore powerful and more expensive pesticides, which in the US, cost 8 billion dollars a year, not counting the cost of spreading them on the land. Similarly, repeated use of herbicides over a period of time results in shift of the weed flora. The weeds of minor importance, often, become major weeds. Repeated use of weedicides leads to development of resistance in weed at alarming proportions.

Soil health degradation

Conventional agriculture alongwith deforestation is the primary cause of devastating soil degradation all over the globe. On a global scale, soils hold more than twice as much carbon (an estimated 1.74 trillion U.S. tons) as does terrestrial vegetation (672 billion U.S. tons) but this pool is dwindling fast due to conventional agricultural practices leading to degradation of soil health. The carbon loss from soil contributes to soil erosion by degrading soil structure, increase vulnerability to drought by greatly reducing the level of water-holding carbon in the soil; and the loss of soil's native nutrient value. Surprising analysis of the USA's oldest continuous cropping test plots in Illinois showed that contrary to long-held beliefs, nitrogen fertilization does not build up soil organic matter (Timothy 2008). Conventional industrial agriculture is getting increasingly unproductive due to soil degradation and the stark evidence of this can be found in the Indo-Gangetic plains South Asia. Long term continuous use of high doses of chemical fertilizers badly affects the physical, chemical and biological properties of the soil. A study carried out at the University of Agricultural Sciences, Bangalore confirmed the deterioration of soil health because of the reduction in water holding capacity, soil pH, organic carbon content and the availability of the trace elements such as zinc in case of ragi crop even with the application of normal doss of fertilizer in the long run (Hegde et al. 1995).

Thus, with foregoing it can be concluded that conventional agriculture is one of the major environmental polluters and therefore to promote the eco-safety as well as agricultural sustainability farmers need to adopt eco-friendly production technologies. Organic agricultural practices are based on a maximum harmonious relationship with nature aiming at the non-destruction of the environment. Naturally, organic agriculture is looked upon as one of the means to remedy these problems associated with conventional agriculture.

Environmental benefits of organic agriculture

Organic agriculture help mitigate and adapt climate change, conserve water quality, promotes biodiversity, soil health etc. Through its holistic nature, organic farming integrates wild biodiversity, agro-biodiversity and soil conservation, and takes low-intensity farming one step further by eliminating the use of chemical fertilizers, pesticides and genetically modified organisms (GMOs), which is not only an improvement for human health (food quality) and agrobiodiversity, but also for the associated off farm biotic communities. Organic agriculture restores the environmental balance and reduces or avoids deleterious effects on the environment.

Climate change mitigation and adaptation through organic agriculture

Organic agriculture could be one of the most powerful strategies in the fight against global warming but so far agriculture is being considered as an undervalued and underestimated climate change mitigation and adaptation tool. Even though climate and soil type affect sequestration capacities, the multiple research efforts verify that regenerative agriculture, if practiced on the planet's 3.5 billion tillable acres, could sequester up to 40 percent of current CO_2 emissions (Timothy, 2008). As stated in the 2002 report of the United Nations Food and Agriculture Organization (FAO), organic agriculture enables ecosystems to better adjust to the effects of climate change and has major potential for reducing agricultural greenhouse gas emissions (Erisman et al.2008). The global potential of nitrogen supply through organic waste recycling and biological nitrogen fixation; which are basic ingredients of organic systems is far bigger than the current production of synthetic nitrogen and, as such can contribute significantly to reduce the GHGs emissions (Williams et al.2006).

Organic agriculture help mitigate climate change in the following ways

Reduces emission of greenhouse gases, especially nitrous oxide, as no chemical nitrogen fertilizers are used and nutrient losses are minimized. Sequesters carbon in soil and plant biomass by promoting more and diversified vegetation on organic farms, encouraging agro-forestry and forbidding the clearance of primary ecosystems. Minimizes energy consumption by 30-70% per unit of land by eliminating the energy required to manufacture synthetic fertilizers, pesticides, growth hormones etc. and by using internal farm inputs, thus reducing fuel used for transportation

Organic agriculture helps farmers adapt to climate change because it

Prevents nutrient and water loss through high organic matter content and soil covers, thus making soils more resilient to floods, droughts and land degradation processes. Preserves seed and crop diversity, which increases crop resistance to pests and diseases. Maintenance of diversity also helps farmers evolve new cropping systems to adapt to climatic changes. Minimizes risk due to stable agro-ecosystems and yields, and lower production costs.

Impact of organic agriculture on greenhouse gas emissions

Organic agriculture is an important climate change mitigation strategy as it reduces emissions of green house gases. N_2O emissions are less as release of N from organic sources is slow enough to be absorbed by growing plants and therefore free N is not available for denitrifying activities. It is usually assumed that 1–2 percent of the nitrogen applied to farming systems is emitted as N_2O irrespective of the form of the nitrogen input. The default value currently used by the Intergovernmental Panel on Climate Change (IPCC) is 1.25 percent, but new research finds considerably lower values, such as for semi-arid areas (Barton et al. 2008). From organically managed fields CO_2 emission is less due to reduced soil erosion because of better soil structure and plant cover. However, the effect of erosion on CO_2 emissions is still controversial (IPCC 2007b; Lal 2004; Van Oost et al. 2004; Renwick et al. 2004). As chemical inputs like fertilizers and pesticides are prohibited on the organic farms, CO_2 emission during their manufacturing using fossil fuels is also precluded. Similarly, methane emission from organically managed livestock farms is less due to less livestock density. Assuming half of all nitrous oxide emissions come from N fertilizers, phasing them out would save 11.56 Mt of CO_2e which is equivalent to another 1.5 percent of the USA's green house gases emissions (Anon 2007c). The total green house gases savings from phasing out N fertilizers amount to 2.5 percent of UK's national emissions (Anon2007c). The UK is not a prolific user of N fertilizers compared to other countries, so globally, it seems reasonable to estimate that phasing out N fertilizers could save at least 5 percent of the world's green house gases emissions. Similar views about reduced N_2O emissions under organic agriculture have also been expressed by FAO (Scialabba and Hattam 2002). This is due to lower chemical N inputs, less N release from organic manures due to lower livestock densities under organic agriculture; higher C:N ratios of applied organic manures giving less readily available mineral

N in the soil as a source of denitrification; and efficient uptake of mobile N, P, K in soils by using cover crops in organic agriculture. Greenhouse gas emissions were calculated to be 48-66 percent lower per hectare in organic farming systems in Europe (Stolze et al.1999), and were attributed to no input of chemical N fertilizers, less use of high energy consuming feedstuffs, and elimination of pesticides as characteristic of organic agriculture. Dabbert (2006) reported that on a per-hectare scale, the CO_2 emissions are 40 to 60% lower in organic farming systems than in conventional ones, whereas on a per-unit output scale CO_2 emissions tend to be higher in organic farming systems. Similar results are expected by experts for N_2O and CH_4 emissions, although to date, no research results exist. 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 which is peculiar in organic agriculture (Mathieu et al. 2006). Calculations of NH_3 emissions in organic and conventional farming systems conclude that organic farming bears a lower NH_3 emission potential than conventional farming systems. Nevertheless, housing systems and manure treatment in organic farming should be improved to reduce NH_3 emissions further.

Impact of organic agriculture on energy use

The FAO report found that, “Organic agriculture performs better than conventional agriculture on a per hectare scale, both with respect to direct energy consumption (fuel and oil) and indirect consumption (synthetic fertilizers and pesticides)”, with high efficiency of energy use. Since 1999, the Rodale Institute’s long-term trials in the United States have reported that energy use in the conventional system was 200 percent higher than in either of two organic systems - one with animal manure and green manure, the other with green manure only - with very little differences in yields (Timothy, 2008).Research in Finland showed that while organic farming used more machine hours than conventional farming, total energy consumption was still lowest in organic systems (Lötjönen, 2003); that was because in conventional systems, more than half of total energy consumed in rye production was spent on the manufacture of pesticides. Similarly, the energy used per kilogram of milk produced was lower in the organic than in the conventional dairy farm, and it also took 35 percent less energy to grow a hectare of organic spring barley than conventional spring barley (Lim Li Ching,2010). Figure 3 illustrates that food energy output per fossil energy input is higher in organically grown maize and soybean than conventionally grown maize and soybean.

Lim Li Ching (2010) reported that on average in the US, about 2 units of fossil fuel energy is invested to harvest a unit of energy in crop. Counting all energy inputs in fossil fuel equivalents in an organic corn system, the output over input ratio was 5.79 (i.e., one can get 5.79 units of corn energy for every unit of energy spent), compared to 3.99 in the conventional system. There was also a total energy input reduction of 31 percent, or 64 gallons fossil fuel saving per hectare. The total mitigation potential of organic sustainable food systems is 29.5 percent of global greenhouse gases emissions and 16.5 percent of energy use, the largest components coming from carbon sequestration and reduced transport from localising food systems. On the most conservative estimates based on these examples, localising food systems alone could save at least 10 percent of CO_2 emissions and 10 percent of energy use globally (Anon 2007c). It takes 35.3 MJ of energy on average to produce each kg of N in fertilizers (Biermann et al. 1999).

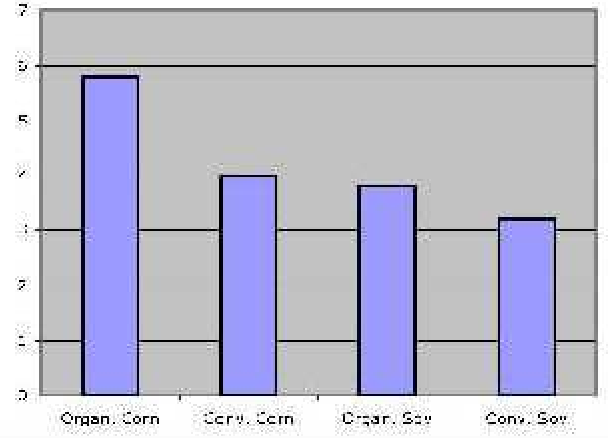


Figure 3 : The food energy output (kcal) per fossil energy input (kcal) for organic corn, conventional corn, organic soybean, and conventional soybean (Source: Pimentel 2006)

Impact of organic agriculture on carbon sequestration : Soils are an important sink for atmospheric CO_2, but this sink has been increasingly depleted by conventional agricultural land use especially due to deforestation. The Stern Review on the Economics of Climate Change commissioned by the UK Treasury published in 2007 (Anon, 2007d) highlights the fact that 18 percent of the global greenhouse gas emissions (2000 estimate) comes from deforestation, and that putting a stop to deforestation is by far the most cost-effective way to mitigate climate change, for as little as $1/ t CO_2 (Saunders, 2007).

Many studies have reported that among the agricultural production systems organic system have greater C sequestration potential. The Sustainable Agriculture Farming Systems (SAFS) Project at University of California Davis in the United States (Clark 1998, 1999) found that organic carbon content of the soil increased in both organic and low-input systems compared with conventional systems, with larger pools of stored nutrients. This was also true in the Rodale Institute trials, where soil carbon levels had increased in the two organic systems after 15 years, but not in the conventional system (Timothy 2008). Based on another study Pimentel (2006) reported that after 22 years organic farming systems averaged 30 percent higher in soil organic matter than the conventional systems (Figure 4).

It is estimated that up to 4 tonnes CO_2 could be sequestered per hectare of organically managed soils each year (Garrett, 2007). On this basis, a fully organic

UK could save 68 Mt of CO_2 or 10.35 percent of its green house gases emissions each year. Similarly, if the United States were to convert all its 65 million hectares of crop lands to organic, it would save 260 Mt CO_2 a year. Globally, with 1.53 billion hectares of crop land fully organic, an estimated 6.13 Gt of CO_2 could be sequestered each year, equivalent to more than 11 percent of the global emissions, or the entire share due to agriculture. Table 3 gives comparative account of carbon loss and gains in different farming systems in long-term field experiments. In the organic plots, carbon was sequestered into the soil at the rate of 875 lbs/ac/year in a crop rotation utilizing raw manure, and at a rate of about 500 lbs/ac/year in a rotation using legume cover crops (Timothy, 2008). He also reported that results from the Compost Utilization Trial (CUT) at Rodale Institute- a 10-year study comparing the use of composts, manures and synthetic chemical fertilizers, revealed that the use of composted manure with crop rotations in organic systems can result in carbon sequestration of up to 2,000 lbs/ac/year. By contrast, fields under standard tillage relying on chemical fertilizers lost almost 300 pounds of carbon per acre per year. Storing or sequestering up to 2,000 lbs/ac/year of carbon means that more than 7,000 pounds of carbon dioxide are taken from the air and trapped in field soil.

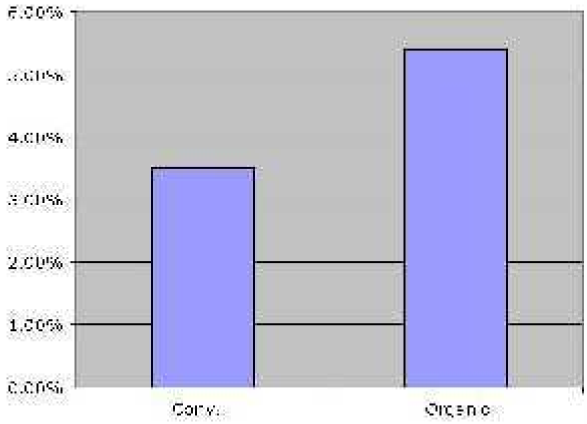


Figure 4 : Soil organic matter in the conventional (a)and organic farming (b)systems after the 22 - year experiments at the Rodale Institute (Source: Pimentel, 2006)

Table 3 : 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
Frick2 Reduced Tillage Trial, Research Institute FiBL, (Switzerland) Running since 2002	Organic, with ploughing	0	100 %
	Organic,with reduced tillage	+ 879	112 %
Rodale FST, Rodale Institute, Kurtztown,	Organic, with farm yard manure	+ 1 218	97 %

Contd. ...

Pennsylvania (USA,) (Hepperly et al.2006; Pimentel et al.2005) Running since 1981	Organic, with legume based green manure.	+ 857	92 %
	Conventional	+ 217	100 %
Scheyern[3] Experimental Farm, University of Munich, Germany, running since 1990 (Rühling 2005)	Organic	+ 180	57 %
	Conventional	- 120	100 %

Besides, climate change mitigation organic agriculture reduces the vulnerability of the farmers to climate change and variability. First, organic agriculture comprises highly diverse farming systems and thus increases the diversity of income sources and the flexibility to cope with adverse effects of climate change and variability, such as changed rainfall patterns. This leads to higher economic and ecological stability through optimized ecological balance and risk-spreading. Second, organic agriculture is a low-risk farming strategy with reduced input costs and, therefore, lower risks with partial or total crop failure due to extreme weather events or changed conditions in the wake of climate change and variability (Eyhorn 2007; Scialabba and Hattam 2002). Higher farm incomes are thus possible due to lower input costs and higher sale prices which eventually enhance coping capacity of the farmers and lowers risk of farmers getting indebted. Risk management, risk-reduction strategies, and economic diversification to build resilience are also prominent aspects of adaptation, as mentioned in the Bali Action Plan (UNFCC 2007). Crops and crop varieties used in organic agriculture are usually well adapted to the local environment. Notwithstanding this potential, more research is needed on how organic agriculture systems perform under increased disease and pest pressures, which are important effects of climate change on agriculture (IPCC 2007c), and on how local crop varieties adapt to climate change and variability. Organic agriculture also seems to perform better than conventional agriculture under water stress conditions (Hepperly et al. 2006; Badgley et al. 2007). Organic agriculture increases soil organic matter content. In consequence, soils under organic agriculture capture and store more water than soils under conventional cultivation (Niggli et al. 2008). Organic agriculture accordingly addresses key consequences of climate change, namely increased occurrence of extreme weather events, increased water stress and drought, and problems related to soil quality (IPCC 2007).

Reduction in water pollution through organic agriculture : It has been observed that organic farming contributes significantly to improve water quality of aquifers and other surface water bodies through reduced non-point source pollution from agriculture. Dabbert (2006) found upto 57% lower leaching rates on per hectare basis from organic fields, however, the rates per ton of produced output were similar or slightly higher in organic fields. As chemical fertilizers and pesticides are not used in organic systems, nutrient and chemical pollution in waterways is significantly reduced. Not only does this translate into long-term cleaner waterways, but it will also save in environmental cleanup costs. Many experiments have found reduced leaching of nitrates from organic soils into ground and surface waters, which are a major source of nitrous oxide. Stoppes et al. (2002) made a comparison between organic and conventional farming and found that nitrate losses from arable crops averaged 47 and 58 kg N ha–1 for organic and conventional farming systems respectively, and concluded that under similar cropping, losses from organic systems are similar or slightly smaller than those from conventional farms following best practice. It has been found that in organic farming only 64 % N, 4 % pesticides, 87% fossil fuel are used compared to integrated farming (Table 4). Kramer et al found that cumulative nitrate leaching was highest from the conventionally fertilized treatment after spring fertilization, followed by the integrated and then the two organic treatments, where leaching rates were not significantly higher than the control (Table 6). However, it has been pointed out that ploughing legume at the wrong time, unfavourable crop rotations, and composting farmyard manure on unpaved surfaces increase the possibility of nitrate leaching in organic farming. However, awareness of the problem and alternative measures have been developed and introduced in practice (CABI). In the emerging scenario of organic farming in India, nitrogen leaching losses have to be assessed and appropriate measures have to be taken, on a case to case basis, to reduce harmful effects on water quality.

Table 4 : 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 Nutrient input	**Unit**	**Organic farming**	**Integrated farming with FYM**	**Organic in % of Integrated farming**
	Kg N total ha^{-1} yr^{-1}	101	157	64
	Kg P ha^{-1} yr^{-1}	25	40	62
	Kg K ha^{-1} yr^{-1}	162	254	64
Pesticide applied	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 2006)

Table 5 : Comparative NO_3 leaching and N_2O emission from different management systems.

Treatments	**NO_3 leaching (fall), µg of NO_3 -Nat 100 cm**	**N_2O (fall) g/ha N_2O-N**	**NO_3 leaching (spring), µg of NO_3 -Nat 100 cm**	**N_2O (spring) g/ha N_2O-N**	**Annual NO_3 leaching µg of NO_3 -Nat 100 cm**
Organic					
Compost	$9.66^{a,b}$	$88.57^{b,c}$	180.13^{a}	330.83^{b}	241.26^{a}
Alfalfa	$9.38^{a,b}$	55.65^{b}	234.11^{a}	316.10^{b}	309.84^{a}
Control	3.73^{a}	16.83^{a}	68.06^{a}	$282.28^{a,b}$	108.47^{a}
Integrated					
$CaNO_3$+compost	14.08^{b}	124.57^{c}	608.26^{b}	327.25^{b}	772.83^{b}
Control	4.43^{a}	19.24^{a}	97.50^{a}	$269.03^{a,b}$	154.85^{a}
Conventional					
$CaCNO_3$	13.08^{b}	125.87^{c}	1092.24^{b}	325.98^{b}	1352.52^{c}
Control	3.41^{a}	30.24^{a}	73.38^{a}	175.70^{a}	130.96^{a}

(Source : Kramer *et al. 2006)*

Note : Significant differences at the 0.05 level (least significant difference) are indicated by different letter in the rows.

Biodiversity promotion through organic agriculture : Organic farming performs better than conventional farming in respect to floral and faunal diversity due to prohibition of synthetic pesticides and N-fertilizers, with secondary beneficial effects on wildlife conservation and landscape. With respect to habitat and landscape diversity, research deficits were identified. Nevertheless, in productive areas, organic farming is currently the least detrimental farming system with respect to wildlife conservation and landscape (Dabbert, 2006). Diverse crop rotations in organic farming provide more habitats for wildlife due to the resulting diversity of housing, breeding and nutritional supply. However, direct measures for wildlife and biotope conservation depend on the individual activities of the farmers. Bengtsson et al. (2005) concluded that "organic farming usually increases species richness, having on average 30% higher species richness than conventional farming systems". However, they also pointed to the high variability among studies. Of the studies examined, 16% showed organic farming to have a negative effect on species richness. They concluded that "the attitude of individual farmers, rather than which farming systems is used, is probably the most important factor determining biodiversity at the farm level". Similarly, Hole et al. (2005) summarized their synopsis on biodiversity stating "The majority of the 76 studies reviewed clearly demonstrates that species abundance and/or richness, across a wide range of taxa, tend to be higher on organic farms than on locally representative conventional farms."

Restoration of soil health through organic agriculture

Organic farming tends to conserve soil fertility better than conventional farming systems. This is mainly due to higher organic matter content and higher biological activity (Dabbert 2006). Therefore, organic farming seems to control erosion more effectively. A more continuous soil cover due to close crop rotations also supports this. As Pimentel (2006) stated that "high level of soil organic matter in organic systems is directly related to the high energy efficiencies observed in organic farming systems; organic matter improves water infiltration and thus reduces soil erosion from surface runoff, and it also diversifies soil-food webs and helps cycle more nitrogen from biological sources within the soil." Organic matter is restored through the addition of manures, compost, mulches and cover crops. Auerswald et al. (2003) performed a large scale modeling exercise to compare the effects of organic and conventional farming on erosion. They found that "on average organic agriculture will cause about 24% less erosion than conventional agriculture." They also pointed to a large variation in extent of erosion for both systems, showing that within both systems erosion could be reduced considerably. This finding is completely in line with the description of Stolze et al. (2000) on the topic of soil erosion. There is the high correlation between increased soil carbon levels and very high amounts of mycorrhizal fungi. These fungi work to conserve organic matter by aggregating organic matter with clay and minerals. The biological support system of mycorrhizal fungi is more prevalent and diverse in organically managed systems than in soils that depend on synthetic fertilizers and pesticides (Timothy 2008). In soil aggregates, carbon is more resistant to degradation than in free form and thus more likely to be conserved. Mycorrhizal fungi produce a potent glue-like substance called glomalin that stimulates increased aggregation of soil particles. This results in an increased ability of soil to retain carbon. Table 6 gives comparative account of soil properties under all bio farms where no chemicals inputs were used and conventionally managed farms. Kramer et al. (2006) recorded higher total N, organic matter, microbial biomass C, microbial biomass N, and enzymatic activities under organic treatment compared to integrated and conventional treatments (Table 8).

Table 6 : Mean value of aggregated soil data from 16 pairs of farms each with organic (bio) and conventional (con) farming.

S.No.	**Soil property**	**All 'bio'farm**	**All 'conventional'farm**
1.	Bulk density (Mg m^{-3})	1.07	1.15^*
2.	Penetration resistance (0 to 20 Mpa)	2.84	3.18^*
3.	Carbon (%)	4.84^*	4.27
4.	Respiration (μlO_2h^{-1})	73.7^*	55.4
5.	Mineralization N (mg kg^{-1})	140.0^*	105.9
6.	Ratio of mineralization N to C (mg kg^{-1})	2.99^*	2.59
7.	CEC (cmol kg^{-1})**	21.5^*	19.6

* = significantly different at $p<0.01$, **= Cation exchange capacity in centimeters of cation charge (=) per kilogram of soil. *Source :* adapted from (Reganold 1995).

Table 7 : Soil biological and chemical properties under different management systems.

Treatment	**Total soil N, ppm**	**Organic matter, %**	**Microbial biomass C**	**Microbial biomass N**	**L- aspara-ginase**	**b-gluco-sidase**
Organic	1955	3.40	512.7	61.0	91.9	192.9
Integrated	1755	3.10	420.8	39.7	63.7	134.4
conventional	1242	2.23	357.7	34.0	59.8	131.4

(Source : Kramer*, 2006)*

Thus we can see organic agriculture works in greater harmony with nature and assures quality food on sustainable basis with much less adverse impacts on natural ecosystem health. Thus promoting organic agriculture means promoting eco-safety, sustainability and better health of human beings and animals.

Conclusion

In the process of producing more food for the burgeoning human population through conventional agriculture, we have created several ecological problems like natural ecosystem degradation, loss of biodiversity, declining soil health, release of harmful agrochemicals in the environment, besides releasing emission of harmful greenhouse gases. As a regenerative production technique organic agriculture can avoid such deleterious effects to varying degrees provided when adopted to larger areas. But efforts should be made so that productivity does not suffer and food security can be ensured. Governments on their parts need to should acknowledge organic agriculture as an effective strategy for environment conservation and agricultural sustainability particularly more so due to the imminent threat of climate change, dwindling biodiversity, water pollution, soil health deterioration etc. Organic agriculture should be included in Kyoto Protocol carbon credit mechanisms so that farmers can get economic incentives and motivated to increasingly follow the organic farming systems. At the same time more research activities need to be undertaken to develop and disseminate organic production techniques.

References

Anon (2007a).Observatory monitoring framework indicator data sheet, Environmental impact: Climate change Indicator DD1: Methane emissions. http:// statistics. defra.gov.uk/esg/ace/dd1_data.htm

Anon (2007b). Executive Summary Inventory of U.S. Greenhouse Gas Emissions and sinks: 1990-2005. http:// www. epa.gov/climatechange/emissions / downloads06 / 07ES.pdf

Anon (2007c) Mitigating Climate Change through Organic Agriculture and Localized Food Systems. Institute of science in society, science society sustainability. http://www.i-sis.org.uk/mitigating ClimateChange.php

Anon (2007d).Organic Agriculture and Biodiversity.http://www.iforgan agriculturem.org / growing_organic/1_arguments_for_organicriculture /environmenta l_benefits / pdfs/ Biodiversity_Leaflet.pdf

Simon Dietz, Chris Hope, Nicholas, Stern, and Dimitri, Zenghelis (2007). A Robust Case for Strong Action to Reduce the Risks of Climate Change. *World Economics*. 8: (1)121-168

Auerswald K., Kainz M., Fiener P. (2003) Soil erosion potential of organic versus conventional farming evaluated by USLE modeling of cropping statistics for agricultural districts in Bavaria. *Soil Use Man*. 19:305-311.

Badgley, C., Moghtader J., Quintero E., Zakem E., Chappell M., Avilez-Vazquez K., Samulon A. and Perfecto. I. (2007) Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems,* 22(2): 86–108.

Barton L, Kiese R, Gatter D, Butterbach-Bahl, K., Buck, R., Hinz, C. and Murphy, D. (2008) Nitrous Oxide Emissions from a Cropped Soil in a Semi-arid Climate. *Global Change Biology* 14: 177–92.

Bengtsson, J., Ahnström, J., and Weibull, A.-C. (2005) The effects of organic agriculture on biodiversity and abundance: A meta-analysis. J. Appl. Ecol. 42:261-269.

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

Biermann S, Rathke, G.W., Hülsbergen, K.J. and Diepenbrock, W. (1999) Energy Recovery by Crops in Dependence on the Input of Mineral Fertilizer, Final Report, European Fertilizer Manufacturers Association, http://www.efma.org/publications/ Energy%20Study/endbericht.pdf

Bunyard, P. (1996) Industrial Agriculture - Driving Climate Change. *The Ecologist* 26 (6): 290-98.

Chhonkar, P.K. (2003). Organic Farming: Science and Belief. *J Soil Sci. Soc. India, Vol.* 51(4) : 365-377.

Clark, M.S., Horwarth, W.R., Shennan, C. and Scow. K.M. (1998) Changes in soil chemical properties resulting from organic and low-input farming practices, *Agronomy Journal*, 90: 662-671.

Clark, S., Klonsky, K., Livingston, P. and Temple, S. (1999) Crop-yield and economic comparisons of organic, low-input, and conventional farming systems in California's Sacramento Valley. *American Journal of Alternative Agriculture* 14: 109-121

Deb, D.L. and Joshi, H.C. (1994) Environment pollution and agriculture, in natural resource management for sustainable agriculture and environment, Angkor publications (P) Ltd., New Delhi, pp. 227-293.

Edward Goldsmith. (2010) How to feed people under a regime of climate change. http://www.edwardgoldsmith.org/page97.html

El-Hage Scialabba, N., and Hattam, C. (2002) Online document. “Organic Agriculture, Environment, and Food Security.” Environment and Natural Resources Service, Sustainable Development Department, Food and Agriculture Organization of the United Nations (FAO). http: // www. fao.org/ docrep / 005 / y4137e /y4137e00.htm.

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.

EFMA (European Fertilizer Manufactures Association). (2005) Understanding Nitrogen and Its Use in Agriculture. EFMA, Brussels, Belgium.

Eyhorn, F. (2007) Organic farming for sustainable livelihoods in developing countries: the case of cotton in india. Ph.D diss. Department of Philosophy and Science, University of Bonn. http://www.zb.unibe.ch/downlorganic agricultured /eldiss /06eyhorn_f.pdf.

FAO. (1998) Crop Genetic Resource, in Special: Biodiversity for Food and Agriculture, FAO, Rome, at: http://www.fao.org/sd/EPdirect/EPre0039.htm (accessed 29/6/05)

FAOSTAT (2009) FAO Statistical Database Domain on Fertilizers: ResourceSTAT-Fertilizers. Food and Agriculture Organisation of the United Nations (FAO) Rome, Italy. Available at http://faostat.fao.org/site/575/default. aspx#anchor

Garrett, T. (2007) Overall UK consumption related GHGs, April 2007, Food Climate change Research Network, http: //www. fcrn.org. uk/ frcnresearch /publications.

Gupta, S. K., Gupta, R. C., Seth, A. K., Bassin, J. R., Gupta, D. K. and Sharma, S. (2000) Recurrent acute respiratory infections in areas with high nitrate concentrations in drinking water. *Environ. Health Prospect*, 108: 363–366.

Hegde, B.R., Krishnegowda, K.T. and Parvathappa, H.C. (1995) organic residue management in red soils under dryland conditions, in Shivashankar, K. (ed.), Alternatives to fertilizers in sustainable agriculture, University of Agricultural sciences, Bangalore.

Hepperly, P., Douds Jr., D. and Seidel R. (2006) The Rodale Farming 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, ed. J. Raupp, C. Pekrun, M. Oltmanns, and U. Köpke, 15–32. Bonn, Germany: International Society of Organic Agriculture Research (ISOFAR).

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

IPCC. (2007a) Synthesis report. In Metz, O.R.D., Bosch, P.R., Dave, R. and Meyer, L.A. (eds). Fourth Assessment Report: Climate Change 2007. Cambridge University Press, Cambridge, UK.

IPCC. (2007b) Summary for Policy Makers. In: IPCC Fourth Assessment Report, Working Group III Report: Mitigation of Climate Change. See specifically on agriculture, chapter 8. http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-spm.pdf and http://www.ipcc.ch/ipccreports/ar4-wg3.htm.

IPCC. (2007c) Summary for Policy Makers.” In IPCC Fourth Assessment Report, “Working Group II Report: Impacts, Adaptation, and Vulnerability. See specifically on adaptation, chapter 17; on inter-relationships between adaptation and mitigation, chapter 18; on vulnerability, chapter 19. http://www.ipcc.ch/pdf/ assessment-report/ar4/wg2/ar4- wg2-spm.pdf and http://www.ipcc.ch/ ipccreports/ ar4-wg2.htm.

Kramer, S. B., Reganold, J. P., Glover, J. D., Bohannan, B. J. M. and Mooney, H. A. (2006) Reduced nitrate leaching and enhanced denitrifier activity and efficiency in organically fertilized soils. *PNAS.* 103 (12):4522–4527.

Lal, R. (2004) Soil Carbon Sequestration Impacts on Global Climate Change and Food Security, *Science* 304: 1623–27. (See also Lal, R., M. Griffin, J. Apt, L. Lave, and G.Morgan. 2004. “Managing Soil Carbon,” *Science 304: 393*; and “Response to Comments on ‘Managing Soil Carbon, *Science* 305: 1567.

Lim Li Ching. (2010) Global Conference on Agriculture, Food Security and Climate Change. http: // www. iatp. Org /climate /files /document / TWN % 20BP % 201_hague % 20ecol%20ag% 20dev%20smart.pdf

Lotjonen T.(2003). Machine work and energy consumption in organic farming. *Ecology and Farming*. 32: 7-8, IFOAM.

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.

Mathieu, O., Lévêque, J., Hénault, C., Milloux, M.-J., Bizouard, F., Andreux, F. (2006) Emissions and spatial variability of N2O, N2 and nitrous oxide mole fraction at the field scale, revealed with 15N isotopic techniques. *Soil Biology & Biochemistry* 38: 941-951.

Moser, A., Schime, D., Valentine, D., Bronson, K., and Parton, W. (1991) Methane and nitrous oxide fluxes in native fertilized and cultivated grassland, *Nature* : 350: 330 - 332

Mosier, A. R. (2002) Environmental challenges associated with needed increases in global nitrogen fixation. *Nutr. Cycl. Agroecosyst.*, 63 : 101–106.

Nadia El-Hage Scialabba and Maria Mu¨ller-Lindenlauf. (2010) Organic agriculture and climate change. *Renewable Agriculture and Food Systems:* 25(2): 158–169

NATCOM, MoEF (2004) India's Initial National Communication (NATCOM) to the UNFCCC was implemented and executed by the Ministry of Environment and Forests, Government of India, funded by the Global Environment Facility under its enabling activities program through the United Nations Development Program, New Delhi. The data has been drawn from a variety of official GoI sources as well as industry association and stakeholder reports.

Niggli, U., Fliessbach, A., Hepperly, P. and Scialabba. N. (2008). Low greenhouse gas agriculture: mitigation and adaptation potential of sustainable farming systems. FAO.

Pimentel, D. (2006) Impacts of Organic Farming on the Efficiency of Energy Use in Agriculture. The Organic Center, Cornell University, Ithaca, NY.

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.

Reganold, J.P. (1995). Soil quality and profitability of biodynamic and conventional farming systems: a review. *American Journal of Alternative Agriculture*. 10(1): 36-45

Renwick, W., Smith, S., Sleezer, R. and Buddemeier, R. (2004) Comment on "Managing Soil Carbon (II)," *Science* 305:5690 (Page 1567c).

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.

Saunders, P,T. (2007) The economics of climate change. Science in Society, 33, 20-23.

Scialabba, NE-H and Hattam, C.(2002) Organic agriculture, environment and food security, FAO, Rome.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B. and Sirotenko, O. (2007) Agriculture. In Climate Change: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 athttp// www. Mnp .nl/ ipcc /pages_media /FAR4docs/ final_pdfs_ar4 /Chapter08.pdf

Stolze, M, Piorr, A., Häring, A. and Dabbert, S. (1999). Environmental and resource use impacts of organic farming in Europe, Commission of the European Communities, Agriculture and Fisheries (FAIR) specific RTD programme, Fair3-CT96-1794, "Effects of the CAP-reform and possible further development on organic farming in the EU".

Stolze, M., Piorr, A., Häring, A., and Dabbert, S. (2000). The environmental impacts of organic farming in Europe, Organic Farming in Europe: *Economics and Policy*, Volume 6. Universität Hohenheim, Stuttgart-Hohenheim.

Stopes, C., Lord, E. I., Phillips, L. and Woodward, L.; (2002). *Soil Use Manage*. 18 (suppl.); 256–263.

Timothy J. L. (2008) Regenerative 21st Century Farming: A Solution to Global Warming. The Rodale institute. Accessed at http :// www. rodaleinstitute. org/ files / Rodale_Research_Paper.pdf

Van Oost, K., Govers, G., Quine, T. and Heckrath. G. (2004). Comment on 'Managing Soil Carbon. *Science*. 305 : 5690 P. 1567 (www.sciencemag.org. content1305/5690/ 1567.2.full.html)

Williams, A.G., Audsley, E. and Sandars, D.L. (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra./ www.silsoe.cranfield.ac.uk, and www.defra.gov.uk.

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