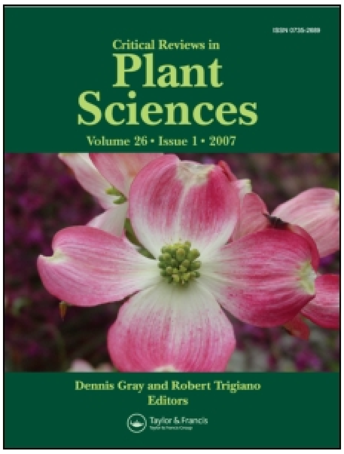

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Energy and Environmental Issues in Organic and Conventional Agriculture

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Energy and Environmental Issues in Organic and Conventional Agriculture

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Humanity is facing possibly the greatest challenge in its history. Population is expected to reach 9 billion in 2030. At the same time agricultural land is becoming scarcer and poorer in quality. Furthermore, the environmental impact of intensive agriculture and the effects of climate change are threatening food security in many regions of the globe. Further, shortage of fossil fuels will have dramatic effects on the performance of intensive agriculture. There is an urge to develop more ecological agricultural practices both to meet the need to preserve agroecosystems health and to deal with the reduced availability of "cheap" energy from fossil fuels. This paper reviews a number of studies comparing the performances of conventional and organic agriculture in light of energy use, CO_2 emission and other environmental issues. Organic agriculture, along with other low input agriculture practices, results in less energy demand compared to intensive agriculture and could represent a means to improve energy savings and CO_2 abatement if adopted on a large scale. At the same time it can provide a number of important environmental and social

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services, such as preserving and improving soil quality, increasing carbon sink, minimizing water use, preserving biodiversity, halting the use of harmful chemicals, thereby guaranteeing healthy food to consumers. We claim that more work should be done in terms of research and investment to explore the potential of organic farming for reducing environmental impact of agricultural practices. However, in the case of organic agriculture, the implications of a reduced productivity for the socioeconomic system should be considered and suitable agricultural policies worked out.

Keywords organic agriculture, conventional agriculture, sustainable agriculture, energy use, GHGs emissions, soil ecology, biodiversity.

I. THE CHALLENGE: IS A MORE ECOLOGICAL AGRICULTURE POSSIBLE?

A. Population, Food Production and Agroecosystems Preservation

At present humanity is facing possibly the greatest challenge in its history. Population is booming and expected to reach 9 billion in 2030 (Smil, 2000; FAO, 2003). At the same time agricultural land is becoming scarcer and its quality poorer. Topsoil is being lost from land areas worldwide 10 to 40 times faster than the rate of soil renewal, threatening soil fertility and future human food security (Pimentel *et al.*, 1995; Pimentel and Kounang, 1998; Pimentel, 2006a, 2007). Desertification is spreading, loss of organic matter in soil increasing and water resources severely reduced. Pollutants from intensive agricultural practices are threatening ecosystems and human health. The effects of climate change are also greatly contributing to threatening food security in many regions of the globe. To this already scaring scenario we have to add the shortage of fossil fuels which, in the near future, will have a dramatic impact on the performances of intensive agriculture (Pimentel and Kounang, 1998; Smil, 2000, 2001, 2003; Tilman *et al.*, 2001, 2002; FAO 2003; Millennium Ecosystem Assessment, 2005; Pimentel and Pimentel, 2007a).

It is evident that new national and global socioeconomic policies have to be worked out to meet this huge challenge. Among these challenges there is surely an urge to develop more ecological agriculture practices (Pimentel *et al.*, 1973, 2005; Wes, 1980; Poincelot, 1986; Paoletti *et al.*, 1989; Altieri, 1987; Rigby and Cáceras, 2001; Srinivasan, 2006; Gliessman, 2007). Recently, also the Millennium Ecosystem Assessment (2005) recommended the promotion of agricultural methods that increase food production without harmful trade offs from excessive use of water, nutrients, or pesticides, while FAO (2002, 2003, 2004) stressed the need to reduce the environmental impact of agriculture practices as it poses a risk to the sustainability of the agriculture and food security itself.

In this sense, organic agriculture represents an option that should be explored because it simultaneously aims to preserve soil fertility, biodiversity, and the landscape's ecological functionality. As stated by FAO (2004, p. iii): "Evidence suggests that organic agriculture and sustainable forest management not only produce commodities but build self-generating food systems and connectedness between protected areas. The widespread expansion of these approaches, along with their integration in landscape planning, would be a cost efficient policy option for biodiversity."

This paper reviews a number of studies comparing the performances of conventional and organic agriculture concerning energy use, CO_2 emission and other environmental issues.

B. The Complex Nature of Agroecosystems

Agroecosystems have been defined as: "... communities of plants and animals interacting with their physical and chemical environments that have been modified by people to produce food, fibres, fuel and other products for human consumption and processing. Agroecology is the holistic study of agroecosystems including all the environmental and human elements. It focuses on the form, dynamics and functions of their interrelationship and the processes in which they are involved." (Altieri, 2002, p. 8).

Agroecosystems interface at different scales with ecosystems (from soil ecology to landscape to global biogeochemical cycles), climate (from local to regional characteristics), economic systems (from local household economy to the global food market), social systems (such as employment opportunities, competition for water use, health risk from agrochemicals use) (Altieri, 1987; Conway, 1987; Giampietro, 2004; Gomiero *et al.*, 2006; Pimentel and Pimentel, 2007a). It has to be stressed that the very same existence of agroecosystems depend on biodiversity in the form of cultivated and wild species (many of which are important for pollination), soil and aboveground organisms which help to preserve soil fertility, recycle organic materials and provide important biocontrol over pests and pathogens.

Because of their nature, agroecosystems play multiple functions that cannot be properly understood by relying upon a single (or few) indicator, be it economic (e.g., US$/ha or US$/hr of work) or biophysical (e.g., energy efficiency per unit of product). In order to gain a proper understanding of agroecosystem performances many criteria (and indicators) have to be considered in parallel and across scales, so that an enlarged picture of the whole system, and of its multifunctionality, can be grasped (Altieri, 1987; Conway, 1987; Paoletti *et al.*, 1989; Ikerd, 1993; Wolf and Allen, 1995; Bland, 1999; Paoletti *et al.*, 1999; Gliessmann, 2000; Kropff *et al.*, 2001; Giampietro, 2004; Pimentel *et al.*, 2005; Gomiero *et al.*, 2006).

C. Organic Farming

Organic agriculture refers to a farming system which has regulations to ban the use of agrochemicals such as synthetic fertilisers and pesticides and the use of GMO, as well as many synthetic compounds used as food additives (e.g., preservatives, coloring) (IFOAM, 2008a, 2008b). Organic agriculture is regulated by international and national institutional bodies, which certify organic products from production to handling and processing (Codex Alimentarius 2004; Courville, 2006; EC, 2007; USDA, 2007; IFOAM, 2008a, 2008b). Its origins can be traced back in the 1920–1930 in North Europe (mostly Germany and UK) (Conford, 2001). Since 1990, with increased public concern for the environment and food quality, the organic farming movement gained attention of consumers and underwent national and international institutional regulation (Willer and Yussefi, 2006). In 2006 there were nearly 31 million of certified organic hectares worldwide distributed as follows: Oceania 43%, Europe 24%, Latin America 16%, Asia 10%, North America 7%, Africa 1% (IFOAM, 2008a, 2008b; Organic World, 2008).

In organic farming systems soil fertility is enhanced by crop rotation, intercropping, polyculture, cover crops, mulching. Pests control is achieved by using appropriate cropping techniques, alley insects and natural pesticides (mainly extracted from plants). Weed control, in many cases the most focal issue for organic farming, is managed by appropriate rotation, seeding timing, mechanic cultivation, mulching, transplanting, flaming, etc. (Altieri, 1987; Lampkin, 2002; Lotter, 2003; Altieri and Nichols, 2004; Koepf, 2006; Kristiansen *et al*., 2006; Gliessman, 2007). As with any manipulation of natural environment, biological control must adopt a cautionary approach when introducing novel organisms to fight pests. Cases have been reported that introduced alley insects turned out to cause more harm than those they were supposed to fight (Simberloff and Stiling, 1996; Hamilton, 2000).

In organic farming, preserving soil biodiversity is essential for the preservation of soil fertility and local biodiversity (both wild and domesticated organisms). The organic philosophy aims at preserving the natural environment; concern towards local floras and fauna as goals for organic farming are often little understood by consumers and policy makers.

Some authors have noted that the pressure of agrifood corporations, that buy and distribute organic products and the market itself, may lead farmers to shift once again into monoculture and industrial agriculture driving farmers away from some of their "environmental friendly" management practices (Guthman, 2004). National and international trade of organic products results also in increasing "food miles" (the distance that food travels from the field to the grocery store) which means increased energy consumption and CO_2 emissions (Pimentel *et al*., 1973; Steinhart and Steinhart, 1974; DEFRA, 2005; Pretty *et al*., 2005; Schlich and Fleissner, 2005; Foster *et al*., 2006; Pimentel and Pimentel, 2007b). To avoid such a problem environmental groups and organic associations are advising consumers to consume locally produced food as part of environmentally friendly eating habits. However, this may turn out to limit exportation from developing countries to western markets reducing the income for poor farmers.

Some authors claim that organic farming, allowing economic savings, can offer an important opportunity for developing countries to produce crops with limited costs and environmental impact, at the same time contributing to reduced food shortage and the detrimental environmental impacts of conventional agriculture (Paoletti *et al*., 1999; Pretty and Hine, 2001; Altieri, 2002; FAO, 2002; Pretty *et al*., 2003; Kristiansen *et al*., 2006; Badgley *et al*., 2007). Pretty and Hine (2001) surveyed 208 projects in developing tropical countries in which contemporary organic practices were introduced. They found that average yield increased by 5–10% in irrigated crops and 50–100% in rainfed crops. However, those claims have been challenged by different authors (e.g., McDonald *et al*., 2005; Cassman, 2007; Hudson Institute, 2007; Hendrix, 2007), who dispute the correctness of both the accounting and comparative methods employed. Hudson Institute (2007) refers that in most of the farming cases accounted as organic by Pretty and Hine (2001) chemical fertilizers and/or pesticides have been regularly applied.

Although there are benefits offered by organic farming, its extensive adoption still meets with a number of difficulties. To deal in detail with such an issue would require an extensive paper in itself. Briefly, we make the following points: (1) organic agriculture requires skilled farmers and competent technicians. Often university programs offer little help in this and perform little research on topics related to organic farming; (2) socioeconomic pressure poses a burden to farmers who, especially in developed countries, are forced to increase the throughput in terms of biomass per hour of work as much as possible, to the point of affecting sustainability of the agroecosystem itself (Giampietro, 1997, Gomiero *et al*., 1997; Pretty *et al*., 2000). This affects more organic producers, whose productivity is usually lower than conventional producers; (3) our system of economic accounting does not take into account the many environmental services provided by organic-based agriculture (soil fertility, biodiversity of wild and domesticated species, landscape quality, water use, pollution, energy savings, Green House Gasses emission, etc.) (Pimentel *et al*., 1995; Pretty, 1995; Pretty *et al*., 2000; Myers and Kent, 2001). Organic farmers, who tend to be more concerned with long-term sustainability, lose out in such an economic approach; (4) national policies provide little economic support to organic agriculture, overlooking the nonmarket values generated by organic farming, in spite of their key importance for the long term sustainability of our agroecosystems and the environment; (5) agricultural subsidies tend to benefit organic farmers less and often have produced adverse effects on the agriculture system as an whole, becoming ineffective in improving farmers lives while causing environmental problems to soar (Pretty *et al*., 2000; Myers and Kent, 2001; van Beers and van den Bergh, 2001; Pye-Smith, 2002); (6) the distribution systems often absorb most of the product value, leaving little to farmers who have very limited trading power when dealing with large companies; (7) consumers are often not informed about the relation among the food they buy in the supermarket and the effects that the system of production has on the agroecosystem and the environment.

To move our agriculture toward a more sustainable path is not an easy task because we need to simultaneously deal with a number of different issues. Eventually it might require our society to change some of its paradigms, for instance our view of "development" and our value accounting system.

D. Other Agricultural Practices Aimed at Sustainable Agriculture

It must be mentioned that, in the last few decades, conventional agriculture also has become more sensitive to the sustainability of farming practices and environmental impact. New regulations by governmental agencies and the cut of production costs have led farmers to limit the use of chemicals and to adopt better tillage practices. In the following sections we will present the concept of sustainable agriculture and some new agriculture practices that are based on such concepts.

According to Kirschenmann (2004), Wes Jackson was the first to use the term Sustainable Agriculture in his publication *New Roots for Agriculture* (1980). The term did not emerge in popular usage until the late 1980s. Sustainable agriculture must, as defined by the U.S. Department of Agriculture in the 1990 Farm Bill: "... over the long term, satisfy human needs, enhance environmental quality and natural resource base, make the most efficient use of nonrenewable resources and integrate natural biological processes, sustain economic viability, and enhance quality of life." (USDA, 1990). Sustainable agriculture does not refer to a prescribed set of practices and it differs from organic agriculture because, in sustainable agriculture, agrochemicals (synthetic fertilizers and pesticides) still play a role. However, their use is kept to a minimum, and conservative practices (crop rotation, integrated pest management, natural fertilization methods, minimum tillage, biologic control) are fully integrated in farm management. Sustainable agriculture should aim at preserving the natural resource base, relying on minimum artificial inputs from outside the farm system, recovering from disturbances caused by cultivation and harvest, while at the same time being economically and socially viable (Poincelot, 1986; NRC, 1986; Dunlap *et al*., 1992; Gliessman, 2007).

Although sustainable agriculture practices are adopted by an increasing number of farmers only organic agriculture is regulated by laws and is required to follow a specific set of norms. A farmer practicing sustainable agriculture can, if in need, spray synthetic pesticides, or add synthetic fertilizers. Within the domain of sustainable agriculture fall some other definitions and practices such as integrated agriculture, precision agriculture and permaculture.

Integrated agriculture is a farming method that combines management practices from conventional and organic agriculture. For instance, when possible, animal manure instead of chemical fertilizer is employed. Pest management (integrated pest management) is accomplished by combining several methods including using crop rotation, the release of parasitoids, cultivating pest-resistant varieties, and using various physical techniques. Pesticides are used as the last resort. Integrated agriculture is not ruled by specific regulations but its goal is still to reduce as much as possible both farm management costs and its environmental impact, aiming at the long-term sustainability of farming practices (Edens, 1984; Poincelot, 1986; Mason, 2003; Pretty, 2005). In some cases groups of farmers can subscribe specific protocols that limit the kind and the amount of chemicals in their farming practices in order to improve the marketability of their products as well as saving on management costs (e.g., fruits producers in some areas in Northern Italy).

Mollison and Holmgren, in their book *Permaculture One: A Perennial Agriculture for Human Settlements* (1978) coined the term *permaculture*, a contraction of "permanent agriculture." Permaculture emphasizes management design and the integration of the elements in a landscape, considering the evolution of landscape over time. The goal of permaculture is to produce an efficient, low-input integrated culture of plants, animals, people and structure, and integration that is applied at all scales from home garden to large farm (see also http://www.permaculture-info.co.uk/).

Precision agriculture (also known as "precision farming," "site-specific crop management," "prescription farming," "variable rate technology") has developed since the 1990s, and refers to agricultural management systems that carefully tailor soil and crop management to fit the different conditions found in each field. Precision agriculture is an information and technology based agricultural management system (e.g., using remote sensing, geographic information systems, global positioning systems and robotics) to identify, analyze, and manage site-soil spatial and temporal variability within fields for optimum profitability, sustainability, and protection of the environment (Lowenberg-DeBoer, 1996; National Research Council, 1998; Srinivasan, 2006). Precision agriculture is now taught in many universities around the world (see for instance http://precision.agri.umn.edu/links.shtml).

However, the fact that the national accounting system tends to overlook, as costs or benefits for farmers and the society as a whole, items such as soil loss, water pollution and depletion, energy use, biodiversity loss, health issues due to chemical contaminants in food and environment, spread of pest resistance, etc., introduces bias in the comparative analyses. When proper analyses are carried out such costs can be very large. For instance, the cost of unsustainable soil management practices in the USA has been estimated to reach 44 billion US$ each year (Pimentel *et al*., 1995). Climatic changes associated with poor rotation of crops, loss of soil organic matter and removal of natural vegetation in the rural landscape, can promote resurgence or incoming of new crop pests causing great economic damage to farmers (Paoletti *et al*., 2007a, 2007b). Overlooking environmental issues can risk the long-term food security of a country (Carter and Dale, 1975; Hillel, 1991; Diamond, 2005; Pointing, 2007). According to the historian Donald Worster (2004) the Dust Bowl that in the 30s hit the USA southern plains, was the dramatic result of soil mismanagement coupled with short sighted rural policies: "The Dust Bowl rightly became the dominant national symbol of this bankruptcy and ecological decay, fusing into itself all the environmental complexities of the time" (Worster, 2004, p. 63).

E. Agroecosystem Analysis: Some Methodological Remarks

Comparing organic and conventional farming systems is not a simple task as they use different approaches to farming. Where organic farming aims as much as possible at self-sustainability, conventional farming can rely much more on external inputs (e.g., chemical fertilizers, synthetic pesticides).

Concerning farming system analysis, the following issues deserve to be carefully dealt with:

1. *Holistic approach*. Often farming system comparisons are based only on economic analysis, or other indicators taken alone, such as yield and economic accounting (e.g., Lockeretz *et al.*, 1981), energy efficiency (e.g., Refsgaard *et al.*,1998), or environmental impact (e.g., Reganold *et al.*, 1987, 1995; Paoletti *et al.*, 1993; Drinkwater *et al.*, 1998; Hansen *et al.*, 2001; Mäder *et al.*, 2002a). There are a few attempts at an integrated analysis based on long-term data (e.g., Reganold *et al.*, 2001; Pimentel *et al.*, 2005; Pimentel, 2006b). Simplifying the focus of farming system analyses risks a true understanding of its complexity. Comparative studies also tend often to focus on specific crops (often a single one) and on a short period of time. Long-term studies (e.g., a minimum of 10 years) should be encouraged to gather information about multiple sustainability of different farming systems.

2. *Energy accounting*. Results from energy assessments are often difficult to compare because of the variety of methodologies and accounting procedures employed (e.g., Stölze *et al.*, 2000; Hansen *et al.*, 2001; Hass *et al.*, 2001; Refsgaard *et al.*, 1998 in Dalgaard *et al.*, 2001). Some authors (e.g., Foster *et al.*, 2006) note that few studies cover the whole "farm to fork" life cycle of the agriculture system in spite of the fact that this is necessary to gain a comprehensive energy analysis of products in the agrifood system.

3. *Internalization of externalities*. We argue that proper analysis should include also the (energetic) cost of "externalities," such as: soil degradation, water consumption, loss of biodiversity, loss of environmental quality and decontamination, the whole CO_2 (and GHGs) emissions due to long distance commodities trade compared to locally grown and consumed organic products, etc. Indicators able to internalize those "hidden" energetic and economic costs should be employed. In this sense comprehensive indicators such as Emergy and the Ecological Footprint may be of great help to address the big picture. Emergy (spelled with an "m") proposed by H. T. Odum (1988, 1996), for instance, is one of the indicators that could help to integrate hidden costs. Emergy is a measure of solar energy used in the past along the way to get the final product or service, and thus different from a measure of the energy content now (e.g., Odum, 1988, 1996; Ulgiati *et al.*, 1994; Ulgiati and Brown, 1998; Haden, 2003). Such an analysis, however, is far from easy to use correctly because of: (1) the complex nature of energy flow [see for instance the critics moved by Maud (2007) to Castellini *et al.*, (2006) who attempted a comparative emergetic assessment using Emergy indicator of two poultry farms in Italy[1]], and (2) the uncertainty that transformity values might have [transformity refers to the energy of one type required to make a unit of energy of another type (Odum, 1988, 1996)]. The Ecological Footprint, since its introduction, by Wackernagel and Rees (Rees, 1992; Wackernagel and Rees, 1996), has gained consensus as an indicator of sustainability. Ecological Footprint assesses human demand on natural resources against the biosphere's ability to regenerate those resources and provide services. Both the Ecological Footprint and the earth's biocapacity, are measured in units of "global hectares," a hectare normalized to the average productivity of all bioproductive hectares on Earth. Ecological Footprint has been applied to a number of case studies (see http://www.footprintnetwork.org) including the assessment of the environmental pressure at local (e.g., cities, regions and nations) and global scale.

To avoid, or better to reduce, bias and/or flaws in the analysis, sound comparisons should embrace a more complex approach where environmental, social and economic criteria are considered at the same time and at different scales (Giampietro *et al.*, 1994; Wolf and Allen, 1995; Gomiero *et al.*, 1997, 2006; McConnell and Dillon, 1997; Bland, 1999; López-Ridaura *et al.*, 2002; Dalgaard *et al.*, 2003; Giampietro, 2004; Laborte *et al.*, 2007).

Energy efficiency and Green House Gasses (GHGs) emission reduction are certainly important indicators of farming system performances, but it has to be pointed out that organic agriculture provides many beneficial "by-products" both for the environment (e.g., eliminating the use of agrochemicals such as synthetic fertilizers and pesticides, increasing organic matter content and conservation of soil fertility, improving the preservation of biodiversity, reducing water consumption) and for human health (e.g., exposure to harmful chemicals, risks from possible side effects of the use of Genetically Modified Organisms in agriculture).

II. ENERGY EFFICIENCY

In this section we will review a number of studies that compare the energy efficiency of organic and conventional farming systems.

A. Energy Analysis

Detailed comparisons of energy performance of organic and conventional farming systems were initiated by Pimentel and colleagues in early 1980s (Pimentel *et al.*, 1983). Since then,

[1]Castellini *et al.* (2006) found an Emergy flow for conventional poultry farm of 724.12 10^{14} solar em joule/cycle, while Emergy flow for organic poultry farm was just 92.16 10^{14} solar em joule/cycle. But productive and economic performances are not mentioned.

TABLE 1
Fossil energy consumption for different crops: organic vs. conventions (based on Stölze *et al*., 2000; FAO 2002 and other references (*))

	Energy consumption (GJ/ha)			Energy consumption (GJ/t)		
Product and reference	Conv.	Organic	Org. as % of conv.	Conv.	Organic	Org. as % of conv.
Winter wheat						
Alföldi *et al*. (1995)	18.3	10.8	−41	4.21	2.84	−33
Haas & Köpke (1994)	17.2	6.1	−65	2.70	1.52	−43
Reitmayr (1995)	16.5	8.2	−51	2.38	1.89	−21
Potatoes						
Haas and Köpke (1994)	24.0	13.1	−46	0.80	0.07	−18
Alföldi *et al*. (1995)	38.2	27.5	−28	0.07	0.08	+7
Reitmayr (1995)	19.7	14.3	−27	0.05	0.07	+29
Mäder *et al*. (2002)[som]	28.42	40.69	−30	3.70	3.98	−7
Citrus						
Barbera and La Mantia (1995)	43.3	24.9	−43	1.24	0.83	−33
Olive						
Barbera and La Mantia (1995)	23.8	10.4	−56	23.84	13.0	−45
Apple						
Geier *et al*. (2001)	37.35	33.8	−9.5	1.73	2.13	+23
Milk						
Cederberg and Mattsson (1998)	22.2	17.2	−23	2.85	2.41	−15
Refsgaard et al. (1998)*	—	—	—	3.34	2.16/2.88	−35/−13
Cederberg and Mattsson (1998) in Haas *et al*. (2001)*	—	—	—	2.85	2.4	−8
Haas *et al*. (1995) in Haas *et al*. (2001) *	19.4	6.8	−65	—	—	—
Haas *et al*. (2001)*	19.1	5.9	−69	2.7	1.2	−54

(som): Supporting Online Material (data from)

the interest for such comparisons increased and a number of works have been produced on the subject, although with different approaches and methodologies that sometimes make results difficult to compare. In Table 1 a number of studies are summarized that compare organic and conventional energetic performances.

Because of the typology of accounting or data reporting, some data found in literature are better summarized in term of ratio of energy input/output. Figures are reported in Table 2.

The data indicates, for most cases, lower energy consumption for organic farming both for unit of land (GJ/ha), from 10% up to 70%, and per yield (GJ/t), from 15% to 45%. The main reasons for higher efficiency in the case of organic farming are: (1) lack of input of synthetic N-fertilizers (which require a high energy consumption for production and transport and can account for more than 50% of the total energy input), (2) low input of other mineral fertilizers (e.g., P, K), lower use of highly energy-consumptive foodstuffs (concentrates), and (3) the ban on synthetic pesticides and herbicides (Lockeretz *et al*., 1981; Pimentel *et al*., 1983, 2005; Refsgaard *et al*., 1998; Cormack, 2000; Haas *et al*., 2001; FAO, 2002; Lampkin, 2002; Hoeppner *et al*., 2006).

It appears that the energetic performances of different farming systems depend on the crops cultured and specific farm characteristics (e.g., soil, climate). For instance, organic potatoes vary from about −20% to + 30% (Table 1). Pimentel *et al*. (1983), who reported lower energy efficiency in organic potatoes, ascribed it to reduced yield due to insect and disease attacks that could not be controlled in the organic system. In the case of apples there is a striking difference between data reported by Pimentel *et al*. (1983) and Reganold *et al*. (2001). This can be brought about by different management techniques and their improvement in the last 20 years.

According to estimates carried out in a study from the Danish government (Hansen *et al*., 2001) upon 100% conversion to organic agriculture a 9–51% reduction in total energy use would result, depending on the level of import of feeds and the amount of animal production.

B. Energy Efficiency Under Extreme Climate

Long-term crop yield stability and the ability to buffer yields through climatic adversity are critical factors in agriculture's

TABLE 2
Comparison of energy efficiency (input/output) per unit of production of organic as % of conventional farming systems (figures from different studies)

Farming system	Reference	Energy efficiency organics as % of conventional
Analysis for crops under organic and conventional management		
wheat in USA	Pimentel *et al*. (1983)	+29/+70
wheat in Germany (various studies)	Stölze *et al*. (2000)	+21/+43
wheat in Italy	FAO (2002)	+25
corn in USA	Pimentel *et al*. (1983)	+35/+47
apples USA	Pimentel *et al*. (1983)	−95
potatoes in Germany (3 studies)	Stölze *et al*. (2000)	+7/+29
potatoes USA	Pimentel *et al*. (1983)	−13/−20
rotations of different production systems in Iran	Zarea *et al*. (2000) (in FAO, 2002)	+81
rotations of different production systems in Poland	Kus and Stalenga (2000) (in FAO, 2002)	+35
Danish organic farming	Jørgensen *et al*. (2005)	+10
whole system analysis (Midwest – USA) with comparable output	Smolik *et al*. (1995)	+60/+70
crop rotations (wheat-pea-wheat-flax and wheat-alfalfa-alfalfa-flax) in Canada	Hoeppner *et al*. (2006)	+20%
Results from Long Term Agroecosystem Experiments		
apples USA	Reganol *et al*. (2001)	+7
various crop systems	Mäder *et al*., 2002	+20/+56%
organic and animals	Pimentel *et al*. (2005)	+28
organic and legumes	Pimentel *et al*. (2005)	+32

ability to support society in the future. A number of studies have shown that, under drought conditions, crops in organically managed systems produce higher yields than comparable crops managed conventionally. This advantage can result in organic crops outyielding conventional crops by 70–90% under severe drought conditions (Lockeretz *et al*., 1981; Stanhill, 1990; Smolik *et al*., 1995; Lotter *et al*., 2003). Others studies have shown that organically managed crop systems have lower long-term yield variability and higher cropping system stability (Smolik *et al*., 1995; Lotter *et al*., 2003).

According to Lotter *et al*. (2003), the primary mechanism for higher yields in organic crops is due to higher water-holding capacity of soils under organic management. Soils in organic plots capture more water and retain more in the crop root zone, up to 100% higher water retention than soils in conventionally managed plots. Such characteristics make organic agriculture an important resource in this present period of climatic variability, especially in developing countries, which are more sensitive to climate extremes. It must also to be mentioned that local specificity plays an important role in determining the performance of a farming system in that what may be sustainable for one region may not be sustainable for another region or area (Smolik *et al*., 1995).

C. A Trade-Off Perspective

In order to gain insight on the sustainability of a farming system, different perspectives such as land use, working time and energy use, should be employed at the same time (Giampietro, 2004). Data on energy efficiency cannot be removed from total energy output and from the metabolism of the social system where agriculture is performed. Great energetic efficiency may imply low total energy output that for a large society with limited land may not be a sustainable option menacing food availability.

Models for energy assessment in Danish agriculture developed by Dalgaard *et al*. (2001) to compare energy efficiency for conventional and organic agriculture, were used to evaluate energy efficiency for eight conventional and organic crop types on loamy, sandy, and irrigated sandy soil. Results from the model indicated that energy inputs were generally about 50% lower in the organic system than in the conventional system and yields also were lower (about 40–60%). Consequently, conventional crop production had the highest yield and energy expenditure while organic crop production had the highest energy efficiency. Similar results were obtained by Cormack (2000) in the United Kingdom, modelling a whole-farm system using typical crop yields. (However, it must be said that, in some long-term trials, yield differences for some crops, in terms of ton/ha, between organic and conventional crops were minimal or negligible; e.g., Reganold *et al*., 2001; Delate *et al*., 2003; Vasilikiotis, 2004; Pimentel *et al*., 2005.)

The inverse relation between total productivity and efficiency is typical for traditional agriculture and intensive agriculture. When comparing corn production in intensive U.S. farming systems and a Mexican traditional farming system the former had an efficiency (output/input) of 3.5:1 while the latter of 11:1 (using only manpower). However, when coming to total net energy production, intensive farming system accounted for 17.5 million kcal/ha yr^{-1}(24.5 in output and 7 in input), while traditional just 6.3 million kcal/ha yr^{-1} (7 million in output and 0.6 million in input) (Pimentel, 1989).

In Europe, the yield from arable crops was 20% to 40% lower in organic systems, whereas the yield for horticultural crops could be as low as 50% that of conventional. Grass and forage production was between 0 and 30% lower for organic systems (Stockdale *et al*., 2001; Mäder *et al*., 2002a, 2002b; ITC-FiBL, 2007). This led Stockdale *et al*. (2001) to conclude that when calculating energy input in terms of unit of physical output, the advantage to organic systems was generally reduced.

When assessing the socioeconomic sustainability of farming enterprises, productivity of labor is a key indicator. Organic farms, although performing better in terms of energy efficiency, generally require more labor than conventional ones, ranging from about 10% up to 90% (in general about 20%), with lower values for organic arable and mixed farms and higher labor inputs for horticultural farms (Lockeretz *et al*., 1981; Pimentel *et al*., 1983, 2005; FAO, 2002; Foster *et al*., 2006). Case studies in Europe for organic dairy farms report a comparable high labour input (FAO, 2002). Little data exists for pig and poultry farms. Again, it must be mentioned that in some long term trials productivity per hectare and hour of work for organic and conventional crops (corn and soybean) were comparable (Pimentel *et al*., 2005; Pimentel, 2006b) (see Table 3).

Figures from Table 3 are very interesting as they compare four key indicators in a 20-year experiment. Data indicates that corn and soybean organic systems perform much better or, at worst, are comparable to conventional systems.

TABLE 3
A comparison of the rate of return in calories per fossil fuel invested in production for major crops –average of two organic systems over 20 years in Pennsylvania (based on Pimentel, 2006b, modified)

Crop	Technology	Yield (t/ha)	Labor (hrs/ha)	Energy (kcal × 10^6)	kcal output/ (input)
Corn	Organic[1]	7.7	14	3.6	7.7
Corn	Conventional[2]	7.4	12	5.2	5.1
Corn	Conventional[3]	8.7	11.4	8.1	4.0
Soybean	Organic[4]	2.4	14	2.3	3.8
Soybean	Conventional[5]	2.7	12	2.1	4.6
Soybean	Conventional[6]	2.7	7.1	3.7	3.2

1) Average of two organic systems over 20 years in Pennsylvania.
2) Average of conventional corn system over 20 years in Pennsylvania.
3) Average U.S. corn.
4) Average of two organic systems over 20 years in Pennsylvania.
5) Average conventional soybean system over 20 years in Pennsylvania.
6) Average of U.S. soybean system.

D. Productivity on a Large Scale

A problem of scale has also to be taken into consideration when it comes to assessing the sustainability of conversion to organic practices. This issue has been openly debated in major scientific journals. In a recent exchange of points of view in *Science*, Goklany (2002), for instance, stated that if typical cereal yields under organic farming are 60 to 70% of those of conventional farming, then between 43 and 67% more land would be needed to keep production constant, further diminishing the environmental and biodiversity advantages of organic farming. In this sense some results from long-term experiments, such as the Rodale Trial (Pimentel *et al*., 2005), are quite encouraging because it reports comparable yields for corn and soybean grown under organic and conventional farming practices. The same has been reported for apple production in the U.S. by Reganold *et al*. (2001).

However, it should be stressed that focusing only on productivity generates misleading conclusions concerning farming system sustainability. Mäder *et al*. (2002) pointed out that agricultural yields have doubled in the last three decades, but worldwide, one third of arable land has been lost to erosion and there has been a dramatic increase in chemical usage and an alarming decline in biodiversity of crops, wild flora and fauna (see the concerns of Krebs *et al*., 1999). Mäder *et al*. (2002) pointed out that the external costs of intensive conventional agriculture have been huge and that, although organic farming may need more land to produce the same yield, it conserves soil, water and biodiversity.

III. CO_2 EMISSION

Because of the role played in CO_2 and other, GHGs (in particular NH_4 and N_2O), emissions by agriculture, it is important to analyze whether organic agriculture offers possibilities to reduce GHG emissions. Agriculture accounted for an estimated emissions of 5.1 to 6.1 Gt CO_2-eq/yr in 2005 (10–12% of total global anthropogenic emissions of GHGs. CH_4contributes 3.3 Gt CO_2-eq/yr and N_2O 2.8 Gt CO_2-eq/yr. Of global anthropogenic emissions in 2005, agriculture accounts for about 60% of N_2O and about 50% of CH4 (IPCC, 2007). Agricultural contributions to CO_2 emissions come from consumption of energy in the form of oil and natural gas, both directly (e.g., field work, machinery) and indirectly (e.g., production and transport of fertilizers and pesticides). Changes in soil ecology also releases carbon into the atmosphere. Deforestation is an important contributor to CO_2 emissions, occurring when forest land is removed to provide more land to plant crops. NH_4 emissions come from livestock, mainly from enteric fermentation but also from manure and rice fields. N_2O comes mainly from the soil (denitrification) and to a lesser extent from animal manure (IPCC, 2007).

A. Carbon Sink Under Organic and Conventional Agriculture: the Production Side

The important role of properly managed agriculture as an accumulator of carbon has been addressed by many authors (e.g., Janzen, 2004; Drinkwater *et al.*, 1998; Pretty *et al.*, 2002; Holland, 2004; Lal, 2004; IPCC, 2007; Keeney, 2007). This carbon can be stored in soil by increasing carbon sinks in soil organic matter and above-ground biomass (e.g., through adopting rotations with cover crops and green manures to increase biomass, agroforestry, conservation-tillage systems, while avoiding soil erosion). It is also possible to reduce direct and indirect carbon emissions, by reducing the use of agrochemicals, pumped irrigation and mechanical power, which account for most of the energy input in agriculture. It has also been suggested that organic farms can develop biogas digesters to produce methane for home and commercial use (Pretty *et al.*, 2002; Hansson *et al.*, 2007)

It is important to evaluate whether organic management can reduce CO_2 . In the last decades CO_2emissions assessment from organic and conventional agriculture has been carried out in different countries with a variety of crops and livestock. Data on CO_2 emissions for several crops and for milk with respect to organic or conventional farming are reported in Table 4.

Figures from Table 4 indicate that CO_2 emissions in organic agriculture are lower on a per hectare scale. However, on a per agricultural output unit scale, results differ. The lower emissions of CO_2 per ha in organic farming can be explained by the lack of agrochemicals (pesticides and in particular of nitrogen fertilizers which production requires high energy inputs) and a lower use of high energy consuming feedstuffs for livestock.

Organic agriculture data for the Global Warming Potential (GWP) of different farming systems, such as methane and NO_x emissions are, in most cases, lacking. A comprehensive accounting is needed due to the high GWP of those gases.

In Table 1, the study of German dairies by Haas *et al.* (2001) reports an energy use for organic agriculture less than half per unit of milk than that from conventional farming and less than one-third per unit of land. There were slightly higher methane emissions per unit of organic produced milk, however, the authors estimated that the final GWP of the two farming systems was similar.

TABLE 4
CO_2 emissions (kg) for some productions [based on Stölze *et al.*, 2000 and other references (*)]

Study	CO_2 emission (kg CO_2 /ha)			CO_2 emission per production unit (kg CO_2/t)		
	Conv.	Organic	Org. as % of conv.	Conv.	Organic	Org. as % of conv.
Winter wheat						
Rogasik *et al.* (1996)	826	443	−46	190	230	+21
Haas/Köpke (1994)	928	445	−57	149	110	−21
Reitmayr (1995)	1001[if]	429	−57	145[if]	100	−21
Potatoes						
Rogasik *et al.* (1996)	1661	1452	−13	46	62	+35
Haas & Köpke 1994)	1437	965	−33	46	48	0
Reitmayr (1995)	1153[if]	958	−17	30[if]	45	+50
Milk						
Lundström (1997)	—	—	—	203	212	+4
Haas *et al.* (2001)*	9400	6300	−67	1280[a]	428[a]	+65%
Haas *et al.* (2001)*				1300[b]	1300[b]	0
Crop management rotation						
Haas and Köpke (1994) in Stölze *et al.* (2000)*	1250	500	−40%	—	—	—
SRU (1996) in Stölze *et al.* (2000)*	1750	600	−34%	—	—	
Rogasik *et al.* (1996) in Stölze *et al.* (2000)*	730	380	−52%	—	—	—

Note: (if): integrated farming; (a) considering only CO_2emission; (b) summing up CH_4 and N_2O emissions as CO_2 equivalents, the CH_4 and N_2O emissions are comparably low, but due to the high Global Warming Potential (GWP) of these trace gases their climate relevance is much higher.

In general, the emissions per ton of food produced is a more relevant indicator to assess the environmental impacts of the farming system because of a lower emission per ha can be achieved However, low yields in many socioeconomic systems do not allow a farm to stay productive. For instance, the production of potatoes in organic farming (Table 4) is associated with lower CO_2 emissions per ha but tends toward higher CO_2 emissions per ton due to a lower productivity. Estimates of the CO_2 emissions per ton of crop give different results depending on the assumption of yield levels. Note the wide range of values of kg CO_2/t, with winter wheat ranging from −21% to +21% and potatoes from 0 to 50%. In such trials annual climatic variation and assumptions in setting up system analysis can play an important role in determining the final figures.

A report by the International Trade Centre of the World Trade Organization and the Research Institute of Organic Agriculture (FiBL) (2007), summing up a number of farm level studies from Northern Europe, reported a reduction of GWP per kg of product ranging from 6% to 30% dependent on the products for organic farming, with peaks reaching 41%. Only in 4 out of 16 studies did GWP increase, ranging from 2 to 53%.

Stölze *et al*. (2000), in their review of European farming systems, saw trends toward lower CO_2 emissions in organic agriculture but were not able to conclude that overall CO_2 emissions are lower per unit of product in organic systems compared to the conventional ones. The authors reported that the 30% higher yields in conventional intensive farming in Europe can compensate the lower CO_2 emissions per unit of products in organic agriculture.

Many authors stressed the importance of energy saving in agriculture and the possible role of organic or sustainable practices to move in this direction (Pimentel *et al*., 1973, 2005; Lockeretz, 1983; Poincelot, 1986; Pimentel and Pimentel, 2007b). Smith *et al*. (2007) estimated a global potential mitigation of 770 MtCO2-eq/yr by 2030 from improved energy efficiency in agriculture and suggested that this may be improved by another 20% by adopting organic agricultural practices.

B. Carbon Sink in Soil

Grandy and Robertson (2007) suggested that there is high potential for carbon sequestration and offsetting atmospheric CO_2 increases by effective management of agriculture land. They estimated that, with a reduction of land use intensity by implementing no-till systems, enhanced carbon storage is possible in the upper 5 cm of soil. Soil carbon fixation is possible for conventional agriculture ranging from 8.9 gC m^{-2} y^{-1} (0.89 t/ha y^{-1}) in row crops to 31.6 gC m^{-2} y^{-1} (3.16 t/ha y^{-1}) in the early successional forage crops. Reductions in land use intensity increases soil C accumulation in soil aggregates.

According to a review carried out by Pretty *et al*. (2002), carbon accumulated under improved management improved CO_2 from 0.3 up to 3.5 tC ha^{-1} yr^{-1}. Schlesinger (1999) proposed that converting large areas of U.S. cropland to conservation tillage, including no-till practices, during the next 30 years, could sequester all the CO_2 emitted from agricultural activities in the United States. Similarly, alternative management of agricultural soils in Europe could potentially provide a sink for about 0.8% of the world's current CO_2 release from fossil fuel combustion.

Lal (2004) has estimated that the strategic management of agricultural soil that is moving from till to no-till farming (also known as *conservation tillage, zero tillage,* or*ridge tillage*), has the potential to reduce fossil-fuel emissions by 0.4 to 1.2 Gt C/yr. This is the reduction of 5% to 15% of the global CO_2 emissions. Evidence from numerous Long Term Agroecosystem Experiments indicates that returning residue to soil rather than removing them, converts many soils from "sources" to "sinks" for atmospheric CO_2 (Rasmussen *et al*., 1998; Lal, 2004).

For the European Union (EU-15), Smith *et al*. (2005) have pointed out that because cropland area was decreasing, carbon sequestration between 1990 and 2000 was rather small or negative. Based on extrapolated trends, they predicted carbon sequestration to be negligible or even negative by 2010. Smith *et al*. (2005) stated that without incentives for carbon sequestration in the future, cropland carbon sequestration under Article 3.4 of the Kyoto Protocol will not be an option in the EU.

C. Carbon Sink in Organic Agriculture

Organic agriculture practices play an important role in enhancing carbon storage in soil in the form of soil organic matter. Results from a 15-year study in the U.S., where three district maize/soybean agroecosystems, two legume-based and one conventional were compared, led Drinkwater *et al*. (1998) to estimate that the adoption of organic agriculture practices in the maize/soybean grown region in the U.S. would increase soil carbon sequestration by 0.13 to 0.30 10^{14} g yr^{-1}. This is equal to 1–2% of the estimated carbon released into the atmosphere from fossil fuel combustion in the USA (referring to 1994 figures of 1.4 10^{15} g yr^{-1}).

In the midwestern U.S., in a 10-year for organic crop systems trial, Robertson *et al*. (2000) reported that organic farming system had about one=third of the net GWP of comparable convention crop systems, but had a 3-fold higher GWP than conventional agriculture under no-till systems. They found no difference in nitrous oxide emissions and methane releases between the three systems. Average soil carbon accumulation was 0 g m^{-2} yr^{-1} in conventional agriculture, 8 g m^{-2} yr^{-1} in organic agriculture and 30 g m^{-2} yr^{-1} conventional no-till plots.

Because the soil has a limit to function as a carbon sink, conversion to organic agriculture only represents a temporary solution to the problem of carbon dioxide emissions. Part of the problem is that fossil fuels are being used at a rapid pace. Foereid and Høgh-Jensen (2004) developed a scenario for carbon sink under organic agriculture. The simulations showed a relatively fast increase in the first 50 years of 10–40 g C m^{-2} y^{-1} on average. This increase then levelled off, and after 100 years it had reached an almost stable level of sequestration.

Although organic agriculture surely represents an important option to reduce CO_2, long term solutions concerning CO_2 and GHGs emission abatement should rely on a more general change of our development path, for instance in containing energy consumption in general.

IV. OTHER KEY ENVIRONMENTAL ISSUES

A. The Soil Organic Matter

Above-ground and below-ground components of ecosystems have traditionally been considered in isolation from one another, but it is now clear that there is strong interplay between them (Wardle *et al*., 2004). Many beneficial insects and parasitoids, for instance, spend underground most of their lifecycle before being active above-ground on the crops; preserving soil quality is, then, of foremost importance to take advantage from those beneficial organims for crop pests control (Paoletti and Bressan, 1996). Stable litters on top of soil can encourage pests such as slugs, but can also provide feed to detritivores and polyphagous predators and parasitoids that can benefit crops (Paoletti and Bressan, 1996). It has been reported that removing shelterbelts in the rural landscape can cause a loss of litter in topsoil and this can lead to a shift of feeding habits among some detritivores such as the case of the slater, *Australiodillo bifrons*, in NSW, Australia, which is becoming a cereal pest (Paoletti *et al*., 2007a, 2007b).

Most of the Soil Organic Matter (SOM) is found in the topsoil (15–25 cm of the A horizon) in the form of decaying leaves and stem. SOM is of key importance for soil fertility (Allison, 1973; Altieri, 1987; Pimentel *et al*., 1995; Pimentel and Kounang, 1998). Fertile soils can contain up to 100 tons of organic matter per hectare (or 4% of the total soil weight), for most soils SOM represents 1–5% of the topsoil (Follett and others 1987; Young 1990; Gliessman, 2007). Conventional agricultural practices that tend to leave soil uncovered for long periods of the year are responsible for topsoil erosion and reduction of its SOM content. The soil removed by either wind or water erosion is 1.3–5.0 times richer in organic matter than the soil left behind (Barrows and Kilmer 1963; Allison 1973). About 95% of the soil nitrogen and 25%–50% of the phosphorus are contained in the SOM (Allison, 1973), and it has been estimated that the reduction of SOM from 1.4% to 0.9% lowered the yield potential for grain by 50% (Libert, 1995).

Intensive agriculture poses a threat to soil ecology in two ways (Allison, 1973; Paoletti and Pimentel, 1992; Pimentel *et al*., 1995; Matson *et al*., 1997; Rasmussen *et al*., 1998; Krebs *et al*., 1999; Paoletti, 2001). First, it accelerates SOM matter oxidation and depletion, and then predisposes soil to increased erosion, leading to the necessary application of nitrogen fertilizers.

Sound organic agriculture has been demonstrated to be effective in preserving soil organic matter and preventing soil erosion. Increasing soil organic matter greatly improves soil quality playing a key role in guaranteeing sustainable crop production and food security (Reganold *et al*., 1987, 1995; Drinkwater *et al*., 1998; Siegrist *et al*., 1998; Mäder *et al*., 2002a; Pretty *et al*., 2002; 2003; Lotter, 2003; Lotter *et al*., 2003; Pimentel *et al*., 2005; Gliessman, 2007). It has to be pointed out that the long-term impact on SOM is influenced by the characteristics of local environment, crop type, input management and cultivation practices. Soils under organic management can face SOM depletion if natural fertilization and land management are not carefully carried out (Gliessman, 2007).

Recently, it has been proposed to use agriculture residues on a large scale for biofuel energy production (Lynd *et al*., 19991; Tilman *et al*., 2006; U.S. Department of Energy, 2006; Goldemberg, 2007; Service, 2007). However, while the energy supply provided by using crop residues would be relatively small (referring to the overall energy consumption of the U.S., it would account only for 1% of the energy consumed as heat energy, Pimentel *et al*., 1981), the effect on the soil ecology would be detrimental (Pimentel *et al*., 1981; Rasmussen *et al*., 1998; Smill, 1999). Crop residues, in fact, play a major role in preserving soil fertility by increasing SOM, and reducing soil erosion. As previously pointed out, SOM has a fundamental role in soil ecology. It improves soil structure, which, in turn, facilitates water infiltration and ultimately the overall productivity of the soil. Further, SOM enhances roots growth, and stimulates the increase of soil biota diversity and biomass. The loss of SOM poses a threat to the long term fertility of soil (Allisoon, 1973; Pimentel and Kounang, 1998; Rasmussen *et al*., 1998; Smill, 1999; Lavelle and Spain, 2002).

The increase in biofuel production in the U.S. is leading to the conversion of the land in the Conservation Reserve Program (CRP) to grow feedstock for biofuels. The CRP provides technical and financial assistance to eligible farmers and ranchers to address soil, water, and related natural resource concerns on their lands in an environmentally beneficial and cost-effective manner (NRCS, 2008). These are highly sensitive lands set aside to conserve soil and biodiversity. Using these lands to grow biofuel crops and especially using crop residues would increase soil erosion and water loss. Thus, the attempt to increase the availability of cheap liquid fuels by the use of such lands can have a detrimental impact on soils and agroecosystems (Kirchhoff and Martin, 2008; Gomiero *et al*., 2008).

B. Biodiversity

The positive role of organic agriculture for preserving biodiversity both in soils and landscapes are reported by many authors (e.g., Dritschillo and Wanner, 1980; Paoletti and Bressan, 1996; Paoletti, 2001; Mäder *et al*., 2002a; Bengtsson *et al*., 2005; Fuller *et al*., 2005; Hole *et al*., 2005; Genghini *et al*., 2006).

Meta-analysis, however, indicated that organic farming often has positive effects on species richness and abundance, but that its effects are likely to differ between organism groups and landscapes (Bengtsson *et al*., 2005; Fuller *et al*., 2005). Bengtsson *et al*. (2005) suggested that positive effects of organic farming on species richness can be expected in intensively managed agricultural landscapes. A review of the literature carried out by Hole *et al*. (2005) confirmed the positive effect of organic farming on biodiversity, but the authors pointed out that such benefits may be achieved also by conventional agriculture when carefully managed. Many factors are involved in characterising the pattern of biodiversity in a specific agricultural area. So, long term, system-level studies of the biodiversity response to organic/conventional farming are needed to assess the relation between management practices and biodiversity (Paoletti *et al*., 1989; Thies and Tscharntke, 1999; Hole *et al*., 2005; Roschewitz *et al*., 2005).

C. Food Quality

Whether organic food is better or equal in terms of quality (e.g., higher content of minerals, vitamins) compared to conventionally produced foods, is also an issue (Adam, 2001; Brandt and Mølgaard, 2001, 2006). Some experts have reported that organic food is not better than conventional, stating that data does not provide significant evidence of differences between the two (Brandt and Mølgaard, 2001, 2006 Trewavas, 2001). Others, however, claimed that differences do exist concerning the content of nutritional elements (such as vitamins and other beneficial micro nutrients) (e.g., Brandt and Mølgaard, 2001, 2006; Heaton, 2001; Winter and Davis, 2006; Mitchell *et al*., 2007). Also the avoidance of ingestion with food of harmful pesticides residues is a benefit (e.g., Curl *et al*., 2003; Lu *et al*., 2006; Winter and Davis, 2006; Halweil, 2007). Some authors have suggested that there is a potential for increased microbiological hazards from organic products (including animals) due to the prohibition of antimicrobial use as there is evidence that the use of pesticides, like herbicides, can decrease the number of toxic chemicals produced by plants (Culliney *et al*., 1992). However, up until now, this hypotheses has not been proven (Brandt and Mølgaard, 2001, 2006; Winter and Davis, 2006; Halweil, 2007).

V. CONCLUSION

Organic agriculture aims at maintaining the long term sustainability of the agroecosystem as a whole, preserving and improving soil quality, minimizing energy and water use, preserving biodiversity, guaranteeing good quality and safe food products to consumers.

The overall environmental impacts of organic agriculture are, in most cases, better or much better than those of conventional agricultural practices. Such superior performances are also reported in reviews such as FAO (2002), Lotter (2003), and Kasperczyk and Knickel (2006), and for long-term monitoring trials such as Reganold *et al*. (1987), Paoletti *et al*. (1993), Matson *et al*. (1997), Drinkwater *et al*. (1998), Mäder *et al*. (2002), Pimentel *et al*. (2005), Badgley *et al*. (2007). However, it has to be pointed out that in some cases the performances of organic farming can vary according to specific crop species and crop patterns and in relation to the environmental context where agricultural activity is performed.

From the present review we can reach the following conclusions:

Energy efficiency and energy savings: Organic agriculture performs much better than conventional concerning energy efficiency (output/input). Generally, however, conventional crop production has the highest total net energy production per unit of cropped land (in some trials the figures were comparable).

CO_2 and GHGs abatement: Organic agriculture represents an important option to supply a carbon sink and GHGs abatement. Soil, however, has a limit to carbon sink. Long-term solutions concerning CO_2 emissions for the global society should be searched for in new energy conservation techniques and strategies. Properly managed, organic agriculture represents an interesting option to reduce energy consumption, CO_2 and other GHG emissions, as well as to preserve soil health and biodiversity.

To carry on extensive long-term trials for diverse crops in diverse areas is of fundamental importance to understand the potential of organic farming as well as to improve farming techniques in general. Investing in organic farming research will help to gain knowledge and experience about best practices for agroecosystem management. Although "organic certification" cannot apply to a farm which uses synthetic fertilisers or even small amount of chemical pesticides, we should recognise the benefits of keeping the use of chemicals at a minimum.

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