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Environmental Impact of Different Agricultural Management Practices: Conventional vs. Organic Agriculture

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Organic agriculture refers to a farming system that enhance soil fertility through maximizing the efficient use of local resources, while foregoing the use of agrochemicals, the use of Genetic Modified Organisms (GMO), as well as that of many synthetic compounds used as food additives. Organic agriculture relies on a number of farming practices based on ecological cycles, and aims at minimizing the environmental impact of the food industry, preserving the long term sustainability of soil and reducing to a minimum the use of non renewable resources. This paper carries out a comparative review of the environmental performances of organic agriculture versus conventional farming, and also discusses the difficulties inherent in this comparison process. The paper first provides an historical background on organic agriculture and briefly reports on some key socioeconomic issues concerning organic farming. It then focuses on how agricultural practices affect soil characteristics: under organic management soil loss is greatly reduced and soil organic matter (SOM) content increases. Soil biochemical and ecological characteristics appear also improved. Furthermore, organically managed soils have a much higher water holding capacity than conventionally managed soils, resulting in much larger yields compared to conventional farming, under conditions of water scarcity. Because of its higher ability to store carbon in the soil, organic agriculture could represent a means to improve CO_2 abatement if adopted on a large scale. Next, the impact on biodiversity is highlighted: organic farming systems generally harbor a larger floral and faunal biodiversity than conventional systems, although when properly managed also the latter can improve biodiversity. Importantly, the landscape surrounding farmed land also appears to have the potential to enhance biodiversity in agricultural areas. The paper then outlines energy use in different agricultural settings: organic agriculture has higher energy efficiency (input/output) but, on average, exhibits lower yields and hence reduced productivity. Nevertheless, overall, organic agriculture appears to perform better than conventional farming, and provides also other important environmental advantages, such as halting the use of harmful chemicals and their spread in the environment and along the trophic chain, and reducing water use. Looking at the future of organic farming, based on the findings presented in this review, there is clearly a need for more research and investment directed to exploring potential of organic farming for reducing the environmental impact of agricultural practices; however, the implications of reduced productivity for the socioeconomic system should also be considered and suitable agricultural policies should be developed.

Keywords organic agriculture, conventional agriculture, sustainability, energy use, GHGs emissions, soil organic matter, carbon sink, biodiversity

I. ORGANIC AGRICULTURE: AN INTRODUCTION

Organic agriculture refers to a farming system that bans the use of agrochemicals such as synthetic fertilizers and pesticides and the use of Genetically Modified Organisms (GMO), as well as many synthetic compounds used as food additives (e.g., preservatives, coloring) (IFOAM, 2008; 2010). 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, 2008; 2010). Its origins can be traced back to the 1920–1930 period in North Europe (mostly Germany and UK) (Conford, 2001; Lotter, 2003; Lockeretz, 2007), and it is now widely spread all over the world.

In this paper we will briefly present the history of organic agriculture and introduce the key characteristics of organic practices and principles. The focus of the paper is, then, to review the main literature on the comparison between organic and conventional agriculture concerning their environmental performances. Some socioeconomic issues will also be addressed.

We are aware that conventional agriculture can adopt low input, environmentally friendly approaches to management (as in systems with reduced or no tillage, or integrated pest management farming). However, the very fact that organic agriculture is strictly regulated allows better comparison of the performances of farming systems with and without agrochemical inputs, and with or without the adoption of certain management practices. The main difficulty in comparisons is the blur definition of conventional practices, which range from traditional polycultures to highly industrial monocultures.

We wish to point out that in the review of the literature we found a number of studies published in gray literature (reports, conference proceedings, etc.) in local/national languages, which are then difficult to both reach and read. In this review we choose to reduce to a minimum the references to gray literature because of the difficulty for the reader to find and check the original works.

A. Organic Principles

The International Federation of Organic Agriculture Movements IFOAM, a grassroots international organization born in 1972, that today includes 750 member organizations belonging to 108 countries, for details see http://www.ifoam.org/index.html), states that: "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." (IFOAM, 2010).

The USDA National Organic Standards Board (NOSB) defines organic agriculture as follows: "Organic agriculture is an ecological production management system that promotes and

enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony." (Gold, 2007).

Organic agriculture relies on a number of farming practices that take full advantage of ecological cycles. In organic farming systems soil fertility is enhanced by crop rotation, intercropping, polyculture, covering crops and mulching. Pest control is achieved by using appropriate cropping techniques, biological control, and natural pesticides (mainly extracted from plants). Weed control, in many cases the main focal problem for organic farming, is managed by appropriate rotation, seeding timing, mechanic cultivation, mulching, transplanting, flaming, etc. (Howard, 1943; Altieri, 1987; Lampkin, 2002; Lotter, 2003; Altieri and Nichols, 2004; Koepf, 2006; Kristiansen *et al*., 2006; Gliessman, 2007). As with any manipulation of a natural ecosystem, biological control must adopt a cautionary approach when introducing novel organisms to fight pests. Cases have been reported where introduced ally insects turned out to cause more harm than those they were supposed to fight (Simberloff and Stiling, 1996; Hamilton, 2000).

According to IFOAM, organic agriculture should be guided by four principles:

- *health*: organic agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible,
- *ecology*: organic agriculture should be based on living ecological systems and cycles, increased soil organic matter, work with them, emulate them and help sustain them,
- *fairness*: organic agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities,
- *care*: organic agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.

IFOAM argues that organic agriculture is a holistic production management system which promotes and enhances agroecosystem health, including biodiversity, biological cycles, and soil biological activity. An organic production system is, then, designed to:

- enhance biological diversity within the whole system,
- increase soil biological activity,
- maintain long-term soil fertility,
- recycle plant and animal waste in order to return nutrients to the land, thus minimizing the use of nonrenewable resources,
- rely on renewable resources in locally organized agricultural systems,
- promote the healthy use of soil, water and air as well as minimize all forms of pollution that may result from agricultural practices,
- handle agricultural products with emphasis on careful processing methods in order to maintain the organic integrity and vital qualities of the product at all stages,
- become established on any existing farm through a period of conversion, the appropriate length of which is determined by site-specific factors such as the history of the land, and type of crops and livestock to be produced.

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.

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."

Concerning environmental performances, some authors warn that organic practices may not be applicable without considering the specific situation. Wu and Sardo (2010) list a number of examples in which the effects of agricultural techniques employed in organic agriculture could result in worse environmental impacts than conventional practices. The authors, for instance, argue that, on sloping land, environmental damages from erosion due to mechanical weed control can be more harmful than that from chemical origin, e.g., spraying with glyphosate [results from Teasdale *et al*. (2007), for organic farming on 15% slope, indicate that if properly managed and in proper condition, organic farming can still provide benefits for soil]. In addition, Wu and Sardo (2010) suggest that mulching with polyethylene sheets (permitted in organic farming) is more polluting than spraying glyphosate, and that flame weeders (permitted in organic farming) are more costly and energy demanding than glyphosate and much less efficient in the control of perennial weeds. It is to be noted that the evaluation of one practice ought to be contextualized, with the consideration of a range of factors that determine good or bad management of a landscape as a whole. For example, mechanical slope weeding on its own may be detrimental while if considered within the farm architecture, its local impact may be compensated with features such as hedges and perennials that ensure overall soil resilience.

Some authors (e.g., Guthman, 2004) argue that as organic farmers enter large distribution system they may be forced to shift once again into monoculture and industrial agriculture. That is because of the pressure from agrifood corporations that buy and distribute their organic products, and from the market itself.

B. Origins and Present Situation

In order to help the reader to better understand the foundation of organic farming, it may be useful to provide a brief sketch of

the history of the organic agriculture movement. For details on this topic we will refer the reader to the extensive works of Conford (2001) and Lockeretz (2007) or, for a more concise summary, to Lotter (2003), Kristiansen (2006), Heckman (2006), and Gold and Gates (2007). Historical information can also be found at the website of the main organic associations such as the British "Soil Association" (http://www.soilassociation.org), or the international IFOAM (http://www.ifoam.org).

The first organized movement by alternative farmers, who wanted to adhere to the traditional way of production refusing the new chemical inputs, appeared in Germany at the end of 1920s. Some tens of farmers, agronomists, doctors and lay people grouped together after attending the lectures of the Austrian philosopher and scientist Rudolf Steiner (who developed also Anthroposophy), in 1924. The experimental circle of anthroposophical farmers immediately tested Steiner's indications in daily farming practice. Three years later a cooperative was formed to market biodynamic products forming the association Demeter (for details see Demeter web page at http://www.demeter.net). In 1928 the first standards for Demeter quality control were formulated. Biodynamic agriculture, as this method is named, is well grounded in the practical aspects of manuring the soil, which is the cornerstone of organic farming, but it also concerns lunar and astrological scheduling, communication with "nature spirits" and the use of special potencies or preparations, that are derived by what might be described as alchemical means (Koepf, 1976; 2006; Conford, 2001). These latter practices are not easily "measurable" in scientific terms, but performance can be assessed using usual agronomic indicators.

While Rudolf Steiner was establishing the roots for the growth of the biodynamic movement, Sir Albert Howard (1873–1947), a British agronomist based in India, was trying to develop a coherent and scientifically based system for preserving soil and crop health. Upon his return to the UK, he worked to promote his new approach (Howard, 1943; Conford, 2001). He was convinced that most agricultural problems were due to soil mismanagement, and that reliance on chemical fertilization could not solve problems such as loss of soil fertility and pest management. He maintained that the new agrochemical approach was misguided, and that it was a product of reductionism by "laboratory hermits" who paid no attention to how nature worked. In his milestone book, *An Agricultural Testament* (1943), Howard described a concept that was to become central to organic farming: "*the Law of Return*" (a concept expressed also by Steiner). The Law of Return states the importance of recycling all organic waste materials, including sewage sludge, back to farmland to maintain soil fertility and the land humus content (Howard 1943; Conford, 2001).

The first use of the word *organic* has been ascribed to Walter Northbourne, the author of *Look to the Land,* an influential book published in 1940 in the UK. Within it, he elaborates on the notion of a farm as an "organic whole," where farming has to be performed as a biologically complete process (Conford, 2001). The term "organic" then, in its original sense, describes a holistic approach to farming: fostering diversity, maintaining optimal plant and animal health, and recycling nutrients through complementary biological interactions.

In 1943 in the UK, Lady Eve Balfour (1899–1990) published the book *The Living Soil*, in which she described the direct connection between farming practice and plant, animal, human and environmental health. The book exerted a significant influence on public opinion, leading in 1946 to the foundation in the UK of "The Soil Association" by a group of farmers, scientists and nutritionists. In the following years, the organisation also developed organic standards and its own certification body. Eve Balfour, who was one of IFOAM's founders, claimed that: "The criteria for a sustainable agriculture can be summed up in one word—permanence, which means adopting techniques that maintain soil fertility indefinitely, that utilise, as far as possible, only renewable resources; to avoid those that grossly pollute the environment; and that foster biological activity throughout the cycles of all the involved food chains" (Balfur, 1977).

In 1940, in an article published in *Fact Digest*, Jerome I. Rodale introduced the term "organic agriculture" in the United States and techniques such as crop rotation and mulching, that have, since then, become accepted organic practices in the United States. Although, the idea of organic agriculture came mostly from the work of Albert Howard. However, Rodale expanded Howard's ideas in his book *Pay Dirt* (Rodale, 1945), adding a number of other "good farming practices."

Since 1990, with increased public concern for the environment and food quality, the organic farming movement has gained the attention of consumers and has undergone national and international institutional regulation (Willer and Yussefi, 2006). According to the recent data by IFAOM (Willer, 2011) there are 37.2 million hectares of organic agricultural land (including in-conversion areas). The regions with the largest areas of organic agricultural land are Oceania (12.2 million hectares—32.8%), Europe (9.3 million hectares—25%), and Latin America (8.6 million hectares—23.1%). The countries with the most organic agricultural land are Australia, Argentina, and the United States. It should be noted that it is difficult to compare figures coming from different countries: most of the area in Australia is pastoral land used for low intensity grazing, therefore one organic hectare in Australia is not directly equivalent (e.g., does not have the same productivity) to one organic hectare in a European country.

In the United States, in 2005, for the first time all 50 states had some certified organic farmland. In 2005, U.S. producers dedicated over 1.6 million ha of farmland to organic production systems: 690,000 ha of cropland and 910,000 ha of rangeland and pasture. California remains the leading State in certified organic cropland, with over 89,000 ha, mostly for fruit and vegetable production (Gold, 2007).

According to the data collected from Willer and Yussefi (2006), the main land uses in organic farming worldwide,

as a percentage of the total global organic area, are as follows:

- 5% permanent crops: land cultivated with crops that do not need to be replanted after each harvest, such as cocoa, coffee; this category includes flowering shrubs, fruit trees, nut trees and vines, but excludes trees grown for wood or timber,
- 13% arable land: land used for temporary crops, temporary meadows for mowing or pasture, market and kitchen gardens and land temporarily fallow (less than five years).
- 30% permanent pasture: land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land),
- 52% certified land the use of which is not known but where wild products are harvested.

C. Organic Standards

Organic farming aims at providing farmers with an income while at the same time protecting soil fertility (e.g., by crops rotation, intercropping, polyculture, cover crops, mulching) and preserving biodiversity (even if tending the local flora and fauna as a goal for organic farming is often little understood by consumers and policy makers), the environment and human health. Broader ethical considerations regarding the above aims have also been made (Halberg *et al*., 2006; IFOAM, 2008).

In Europe, the first regulation on organic farming was drawn up in 1991 (Regulation EEC N° 2092/91 – EEC, 1991). Organic standards prohibit the use of synthetic pesticides and artificial fertilizers, the use of growth hormones and antibiotics in livestock production (a minimum usage of antibiotics is admitted in very specific cases and is strictly regulated). Genetically modified organisms (GMOs) and products derived from GMOs are explicitly excluded from organic production methods.

A revised EU regulation which came into force in 2007 (EC, 2007) added two main new criteria: firstly, food will only be able to carry an organic logo (certified as organic) if at least 95% of the ingredients are organic (nonorganic products will be entitled to indicate organic ingredients on the ingredients list only); secondly, although the use of GMOs will remain prohibited, a limit of 0.9 percent will be allowed as accidental presence of authorised GMOs.

In the United States, Congress passed the Organic Foods Production Act (OFPA) in 1990. The OFPA required the U.S. Department of Agriculture (USDA) to develop national standards for organically produced agricultural products, to assure consumers that agricultural products marketed as organic meet consistent, uniform standards. The OFPA and the National Organic Program (NOP) regulations require that agricultural products labelled as organic originate from farms or handling operations certified by a state or private entity that has been accredited by USDA (Gold, 2007).

Internationally, organic agriculture has been officially recognised by the Codex Alimentarius Commission (CAC).[1] In 1991, the CAC began elaborating guidelines for the production, processing, labelling and marketing of organically produced food, with the participation of observer organizations such as IFOAM and the EU. The CAC approved organic plant production in June 1999, followed by organic animal production in July 2001. The requirements in these CAC Guidelines are in line with IFOAM Basic Standards and the EU Regulation for Organic Food (EU Regulations 2092/91 and1804/99). There are, however, some differences with regard to the details and the areas, which are covered by the different standards.

In the Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods, CAC at point 5 states that: "Organic Agriculture is one among the broad spectrum of methodologies which are supportive of the environment. Organic production systems are based on specific and precise standards of production which aim at achieving optimal agroecosystems which are socially, ecologically and economically sustainable." (Codex Alimentarius, 2004, p. 4).

Some authors (e.g., Vogl *et al*., 2005; Courville, 2006) express concerns about the excessive bureaucratic control posed by standards on farmers, and warns that excessive bureaucratization of organic agriculture can result a serious burden to organic farmers because of the economic effort that it takes to accomplish with all the requirements.

II. SOME ISSUES CONCERNING COMPARATIVE ANALYSIS

Often, different approaches to farming system analysis are employed by different scholars, making comparison of findings difficult: this is especially true with regards to how the boundaries of the farming system are defined. For instance, in accounting for the energy in animal feed or agrochemicals, should we consider the energy spent for transportation? In a time of fast globalization where commodities travel from continent to continent such a question is not a negligible one.

Moreover, farming system may have different geographical, climatic and soil characteristics, different crops, different rotation systems (both in crop species and timing) and different sort of inputs.

Comparative studies tend to focus on specific crops, over a short period of time. Simplifying the focus of the farming system analysis, through single commodity versus whole farm productivity analysis, entails the risk of compromising the understanding of its complex reality and supplying incomplete

[1]The Codex Alimentarius Commission was created in 1963 by FAO and WHO to develop food standards, guidelines and related texts such as codes of practice under the Joint FAO/WHO Food Standards Program. The main purposes of this Program is protecting consumer health, ensuring fair trade practices in the food trade, and promoting coordination of all food standards work undertaken by international governmental and non-governmental organizations. (Codex Alimentarius web page at http://www.codexalimentarius.net/web/index_en.jsp)

information. Longer-term studies (e.g. a minimum of 10 years) should be encouraged to gather information—through comparable models—about the true sustainability of different farming systems.

Energy analysis in agriculture is a complex task (Fluck and Baird, 1980; Giampietro *et al*., 1992; Pimentel and Pimentel, 2008; Wood *et al*., 2006; Smil, 2008). Usually energy analysis focuses on fertilizers, pesticides, irrigation and machinery but fails to include important components such as insurance, financial services, repairs and maintenance, veterinary and other services (Fluck and Baird, 1980). Energy efficiency assessment presents many tricky issues (Giampietro *et al*., 1992; Giampierto, 2004; Smil, 2008), and the choice of the system boundary can account for differences as large as 50% on energy estimates among studies (Suh *et al*., 2004; Wood *et al*., 2006), and even higher when coming to the assessment of the whole agri-food system (Giampietro, 2004). Comparing organic and conventional systems is even more difficult (Dalgaard *et al.*, 2001; Haas *et al*., 2001; Pimentel *et al.*, 2005; Küstermann *et al.,* 2008; Thomassen *et al*., 2008; Wu and Sardo, 2010).

Wood *et al*. (2006), for instance, when studying a cohort of organic farmers in Australia, found that when direct energy use, energy related emissions, and greenhouse gas emissions are measured they are higher for the organic farming sample than for a comparable conventional farm sample. But when the whole Life-Cycle Assessment was considered, including the indirect contributions of all above-mentioned secondary factors, then conventional farming practices had a higher energy cost. The authors argue that indirect effects must be taken into account when considering the environmental consequences of farming, in particular with regards to energy use and greenhouse gas emissions. In a comprehensive Life-Cycle Assessment of milk production in The Netherlands, Thomassen *et al.* (2008) compared energy consumption (MJ kg^{-1} of milk) for conventional and organic milk (see also Table 5a and Table 5b). They found that when comparing direct energy consumption conventional performed much better (0.6 MJ kg^{-1} of milk) then organic (0.96 MJ kg^{-1} of milk). But when indirect costs were taken into account, the result was the opposite (conventional 4.47 MJ kg^{-1} of milk and organic 2.17 MJ kg^{-1} of milk). See also Küstermann *et al*. (2008) in section VB for another example concerning GHGs emissions.

Comparing efficiency may not be that simple also within the same experiment. For instance, Gelfand *et al.* (2010) report that an alfalfa growing organic system was half as efficient compared to a conventional system when employing tillage, and had one third of a conventional system efficiency when there was no tillage. But the fact that the authors accounted all the grain (included corn, and soybean) as used directly for human consumption, while alfalfa were not (of course) can be questioned. And, in fact, as the authors correctly argue (Gelfand *et al.,* 2010, p. 4009-4010): "This is because under the Food scenario alfalfa biomass can be used only as ruminant livestock feed and conversion efficiency of forage energy to weight gain by livestock is 9:1. Were we to assume that corn, soybean, and wheat were to be used for livestock production rather than direct human consumption, similar energy conversion efficiencies by livestock would apply. This would result in about 87% lower energy output from the grain systems, similar to Alfalfa energy yields."

This is an important consideration to keep in mind because in an organic farming system the value of a crop has to be understood within a whole cropping system that can span several years. On the contrary, conventional farming can be based on a simple system that alternates corn and soybean on a yearly basis.

To carry on extensive long-term trials for a number of crops in several different geographical areas would be of fundamental importance to understand the potential of organic farming as well as to improve farming techniques in general (Mäder *et al.*, 2002; Pimentel *et al*., 2005; Gomiero *et al*., 2008; Francis *et al*., this issue).

When comparing organic vs. conventional system "farm-to-fork" we should also be aware that a possible disadvantage of organic products is the fact that they account for less than 2% of global food retail: this smaller economic scale compared to conventional systems could contribute to lower energy efficiency of collection, preparation and distribution (El-Hage Scialabba and Müller-Lindenlauf, 2010).

III. SOIL BIOPHYSICAL AND ECOLOGICAL CHARACTERISTICS

In this section we will review the effects of organic agriculture on soil biophysical and ecological characteristics and how these effects relate to the long-term soil fertility. Attempts to develop a soil quality index can provide an effective framework for evaluating the overall effects of different production practices (organic, integrated, conventional etc.) on soil quality (Glover *et al.*, 2000; Mäder *et al*., 2002a; Marinari *et al.*, 2006; Fließbach *et al*., 2007).

A. Soil Erosion and Soil Organic Matter

Soil erosion and loss of Soil Organic Matter (SOM) with the conversion of natural ecosystems to permanent agriculture are the most important and intensively studied and documented consequences of agriculture (Hillel, 1991; Pimentel *et al*., 1995; Lal, 2004, 2010; Montgomery, 2007a; 2007b; Quinton *et al.*, 2010). Intensive farming exacerbates these phenomena, which are threatening the future sustainability of crop production on a global scale, especially under extreme climatic events such as droughts (Reganold *et al*., 1987; Pimentel *et al*., 1995; Mäder *et al.*, 2002a; Sullivan, 2002; Lotter *et al*., 2003; Montgomery, 2007a; 2007b; Lal, 2010; NRC, 2010).

Clark *et al*. (1998) underlined that increases in SOM following the transition to organic management occur slowly, generally taking several years to detect. This is a very important point to be kept in mind when assessing the performances of farming systems under different management practices. Farmers, scientists and policy makers alike should take into consideration

the evolving and complex nature of organic farming systems, a complex nature that contrasts with the extreme simplification and large dependency on external input that characterize conventional farming systems. When aiming at long-term sustainability, trade offs should also be considered between obtaining short-term high yields with the aid of agrochemicals, and maintaining soil health.

Given the crucial importance of soil health, the aim of organic agriculture is to augment ecological processes that foster plant nutrition yet conserve soil and water resources. Even if the soil characteristics are generally site-specific, to date many studies have proven organic farming to perform better in preserving or improving soil quality with regards to both biophysical (e.g., SOM) and biological (e.g., biodiversity) properties (e.g., Reganold *et al*., 1987; Reganold, 1995; Clark *et al*., 1998; Drinkwater *et al.*,1998; Siegrist *et al*., 1998; Fließbach *et al*., 2000; 2007; Glover *et al*., 2000; Stölze *et al*., 2000; Stockdale *et al*., 2001; Mäder *et al*., 2002a; Lotter *et al*., 2003; Delate and Cambardella, 2004; Pimentel *et al*., 2005; Kasperczyk and Knickel, 2006; Marriott and Wander, 2006; Briar e*t al*., 2007; Liu *et al*., 2007).

Although few in number, important long-term studies concerning SOM content and soil characteristics in organic and conventional soils have been carried out, both in the United States and Europe. In a long trial of nearly 40 years, Reganold *et al*. (1987) compared soils from organic and conventional farms in Washington, USA. They found that organic fields had surface horizon 3 cm thicker and topsoil 16 cm deeper than conventionally managed fields. Higher SOM matter content (along with other better biochemical performance indicators) resulted in much reduced soil erosion. In addition, soils under organic management showed $<75\%$ soil loss compared to the maximum tolerance value in the region (the maximum rate of soil erosion that can occur without compromising long-term crop productivity or environmental quality -11.2 t ha^{-1} yr^{-1}), while in conventional soil a rate of soil loss three times the maximum tolerance value was recorded.

As a result of the Rodale Institute Farming System Trial, Pimentel *et al*. (2005) reported that after 22 years the increase of SOM was significantly higher in both organic animal and organic legumes systems, where soil carbon increase by 27.9% and 15.1% respectively, when compared to the conventional system, where the increase was 8.6%. Moreover, soil Carbon (C) level was 2.5% in organic animal, 2.4% in organic legume and 2.0% in the conventional system.

In a 12-year trial in Maryland, Teasdale *et al*. (2007) found that organic farming can provide greater long-term soil benefits than conventional farming with no tillage, despite the use of tillage in organic management. A drawback of the organic system was the difficulty in controlling weeds, explained by the authors by a number of factors such as short crop rotation and remaining crop residues (Teasdale *et al*., 2007; Cavigelli *et al*., 2008). However, the authors argue that despite poor weed control, the organic systems improved soil productivity significantly as measured by corn yields in a uniformity trial conducted in the American Mid-Atlantic region. The same study also indicates that supplying adequate nitrogen (N) for corn and controlling weeds in both corn and soybean are the biggest challenges to achieving equivalent yields between organic and conventional cropping systems (Cavigelli *et al*., 2007). SOM increase for organic soil has been reported also by Marriott and Wander (2006) in a long-term U.S. trial.

In the longest trial so far (running for more than 150 years), and going on at the Rothamsted Experimental Station in the UK, SOM and soil total N levels have been reported to have increased by about 120% over 150 years in the organic manured plots, and only by about 20% in the plots employing NPK fertilizer. Yields for organic wheat have averaged 3.45 t ha^{-1} on organically manured plots, compared with 3.40 t ha^{-1} on plots receiving NPK (Tilman, 1998). Long-term trials in Poland (Stalenga and Kawalec, 2008) also report consistent increase of SOM under organic management.

Different findings have also been reported. In an 18-year-long study in Sweden, Kirchmann *et al*. (2007, did not find significant differences in soil carbon for organic systems compared to conventional systems. It is to be considered that some can be increased up to a certain level where it starts leveling-off.

B. Soil Chemical Properties

In an 8-year experiment in the California's Sacramento Valley, Clark *et al*. (1998) found that the transition from conventional to organic farming improved soil fertility by increasing soil organic C and the pools of stored nutrients. In Europe, a 21-year Swiss field study on loess soil analyzed the agronomic and ecological performance of biodynamic, organic, and conventional farming systems (Siegrist *et al*., 1998; Mäder *et al*., 2002a; Fließbach *et al*., 2007). The authors found that the aggregate and percolation stability of both bio-dynamic and organic plots were 10 to 60% higher than conventionally farmed plots. This also affected the water retention potential of these soils in a positive way and reduced their susceptibility to erosion. Soil aggregate stability was strongly correlated to earthworm and microbial biomass, important indicators of soil fertility (Mäder *et al*., 2002a). The long-term application of organic manure positively influenced soil fertility at the biological, chemical and physical level, whereas the repeated spraying of pesticides appeared to have negative effects. Compared to stockless conventional farming (mineral fertilizers, herbicides and pesticides), the aggregate stability in plots with livestock-based integrated production (mineral and organic fertilizers, herbicides and pesticides) was 29.4% higher, while in organic and bio-dynamic plots (organic fertilizers only) was 70% higher. The authors underline the importance of using manure, by means of organic agriculture, as a good practice for soil quality preservation (Fließbach *et al*., 2007). In addition, planting cover crops once the crop is harvested helps prevent soil erosion, as the soil is kept covered with vegetation all year long.

In North Carolina, Liu *et al*. (2007) found that soils from organic farms had improved soil chemical factors and higher levels of extractable C and N, higher microbial biomass carbon and nitrogen, and net mineralizable N. In Italy, Russo *et al*., (2010) comparing chemical and organic N uptake by crops, found that altogether more mineral N was released in soil and water from the organic fertilizer while more N was taken up by plants with the mineral fertilizer. While microbial population in the soil was unaffected by the type and amount of fertilizers, enzymatic activity responded positively to organic N and was depressed by the synthetic N form. According to Walden *et al*. (1998), organically managed soils may also use mineral nutrients in a more efficient manner and allow lower inputs.

C. Nitrogen Leaching

Nitrogen fertilizers are of key importance in intensive conventional agriculture. However, their use turns out to be a major cause of concern when coming to environmental pollution. The primary source of N pollution comes from N-based agricultural fertilizers, whose use is forecast to double or almost triple by 2050 (Tilman *et al*., 2001; Robertson and Vitousek, 2009; Vitousek *et al*., 2009).

A proportion of soluble N leaches deep into groundwater, ultimately affecting human health, whereas other soluble N volatilizes (e.g., NO_X) to increment GHGs. Considering that nitrous oxide is the most potent GHG and given the environmental problems associated with the production and use of synthetic fertilizer, there is a great need for researchers concerned with global climate change and nitrate pollution to evaluate reduction strategies (Tilman *et al.*, 2002; Millenium Ecosystem Assessment, 2005a; Robertson and Vitousek, 2009; Vitousek *et al*., 2009).

On average, agricultural system N balances (N input vs. N removed with crops) in the developed or rapidly developing worlds are positive (200–300 kg N yr^{-1}), implying substantial losses of N to the environment. A number of practices can be implemented in order to reduce N loss. In this regard, leguminacae can be used productively as cover crops, absorbing N through N_2 fixation and building SOM, and in some cases can also be used by intercropping. The development of crop varieties with higher efficiencies of N uptake could help capture more of the N added to annual cropping systems (e.g., Robertson and Vitousek, 2009; Vitousek *et al*., 2009). Techniques to reduce N loss and to increase the efficiency of N uptake are widely used in organic farming (Drinkwater *et al*.,1998; Lampkin, 2002; Kramer *et al.*, 2006), and many trials demonstrate the benefit of organic farming in reducing N leaching and increasing N uptake efficiency.

A 9-year trial has been conducted by Kramer *et al.* (2006) in commercial apple orchards in Washington State, USA. The study examined denitrification and leaching from organic, integrated, and conventional systems receiving the same amount of N inputs but in different forms. The authors found that annual nitrate leaching was 4.4–5.6 times higher in conventional plots than in organic plots, where microbial denitrifier activity is enhanced through C inputs as organic fertilizers, crop residues, or root exudates from cover crops. Integrated plots showed, intermediate leaching, somewhere between organic and conventional plots. This study demonstrates that organic and integrated fertilization practices support more active and efficient denitrifier bacterial communities and reduce environmentally damaging nitrate losses.

Drinkwater *et al*. (1998) reported better N uptake efficiency for organic systems, and argued that there are differences in the partitioning of nitrogen from organic versus mineral sources, with more legume-derived nitrogen than fertilizer-derived nitrogen immobilized in microbial biomass and SOM, so reducing leaching of NO_3^- of 60% compared to the conventional control. Küstermann *et al.* (2010) report a reduction of N loss in organic farming, compared with the conventional system. An 18-year field study in Swedenby Kirchmann *et al.* (2007) reports different results. The authors found that N leaching is not reduced in organic farming, even with use of cover crops. The authors argue that yield and soil fertility were superior in conventional cropping systems under cold-temperate conditions.

Possible drawbacks from organic fertilization have been reported by some authors (e.g., Tilman *et al*., 2002; Sieling and Kage, 2006; Kirchmann *et al*., 2007; Wu and Sardo, 2010): the 'slow release' of nutrients from organic compost or green manures can be difficult to control and harness and may fail to match crop demand, resulting in N losses through leaching and volatilization. Moreover, in organic systems, competition with weeds can greatly reduce N intake efficiency (Kirchmann *et al*., 2007).

Atmospheric nitrous oxide (N_2O) is a greenhouse gas nearly 300 times more effective at radiative warming than CO_2, and is produced mainly during the microbially mediated process of denitrification. There has been a marked increased in atmospheric N_2O over the past 150 years; about 80% of this source is associated with agriculture, largely (50%) with fertilized soils (Tilman *et al*., 2001; Robertson and Vitousek, 2009; Vitousek *et al*., 2009). Although N_2O contributed for only about 6% to of the global waring potential, it plays a substantial role in the agricultural contribution to climate change, and its emissions can offset efforts to use agricultural systems to mitigate climate change by sequestering CO_2 or providing alternative energy sources (Robertson and Vitousek, 2009)

Works by Mathieu *et al.* (2006) support the hypothesis that an increase in soil available organic carbon leads to N_2 emissions as the end product of denitrification, whilst Petersen *et al.* (2006), in a study concerning five European countries, found that N input is a significant determinant for N_2O emissions from agricultural soils, and that N_2O emissions from conventional crop rotations were higher than those from organic crop rotations (except in Austria), with significant differences between locations

and crop categories. Stalenga and Kawalec (2008) found that N_2O emission for organic farming systems was about 66% lower than conventional systems and 50% lower than integrated systems.

In a long-term study in southern Germany, Flessa *et al.* (2002) also found reduced N_2O emission rates in organic agriculture, although yield-related emissions were not reduced. Contrasting result are reporter by Bos *et al.* (2006, in Niggli *et al.*, 2009) with a reduction of the GHGs on Dutch organic dairy farms and in organic pea production areas, and higher GHGs emissions for organic vegetable crops (e.g., leek and potato).

TABLE 1
The Rodale Institute Farming System Trial, crops performance under drought condition, data after Pimentel *et al.* (2005).

	Yield (kg ha^{-1})	
Farming system	Corn	Soybean
Organic animal	1, 511	1, 400
Organic legume	412	1, 800
Conventional	1, 100	900

D. Water Use and Resistance to Drought

Water use efficiency is determined by the amount of crop yielded divided by the amount of water used (Stanhill, 1986; Morison *et al*., 2008). Several ways to improve water use efficiency in organic agriculture have been proposed, including reducing evaporation through minimum tillage, mulching, using more water-efficient varieties and inducing microclimatic changes to reduce crop water requirements (Stanhill, 1986; Pretty *et al.,* 2006; Morison *et al*., 2008). Sustainable agricultural practices can be effective in improving water use efficiency in particular in poor developing country affected by water scarcity (Pretty *et al.,* 2006). Organic farming proves to be effective both at enhancing soil water content and improve water use efficiency.

Long-term crop yield stability and the ability to buffer yields through climatic adversity will be critical factors in agriculture's capability 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 out-yielding conventional crops by 70–90% under severe drought conditions (Lockeretz *et al*., 1981; Stanhill, 1990; Smolik *et al*., 1995; Teasdale *et al*., 2000; Lotter *et al*., 2003; Pimentel *et al*., 2005). 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. 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).

As part of the Rodale Institute Farming System Trial (from 1981 to 2002), Pimentel *et al*., (2005) found that during 1999, a year of extreme drought, (with total rainfall between April and August of 224 mm, compared with an average of 500 mm) the organic animal system had significantly higher corn yield (1,511 kg per ha) than either organic legume (412 kg per ha) or the conventional (1,100 kg per ha) systems.

For soybean both organic systems performed much better than the conventional system (Table 1).

Pimentel *et al*. (2005) estimated the amount of water held in the organic plots of the Rodale experiment in the upper 15 cm of soil at 816.000 liters per ha. In heavy loess soils in a temperate climate in Switzerland water holding capacity was reported being 20 to 40% higher in organically managed soils than in conventional ones (Mäder *et al.*, 2002a).

The primary reason for higher yield in organic crops is thought to be due to the higher water-holding capacity of the soils under organic management (Reganold *et al*., 1987; Sullivan, 2002; Lotter *et al*., 2003). Soils in the organic system capture more water and retain more of it, up to 100% higher in the crop root zone, when compared to conventional. Such characteristics make organic crop management techniques a valuable resource in this present period of climatic variability, providing a better buffer to environmental extremes, especially in developing countries.

A soil's texture (the proportions of sand, silt, and clay present in a given soil), and aggregation (how the sand, silt, and clay come together to form larger granules) determine air and water circulation, erosion resistance, looseness, ease of tillage, and root penetration. Texture is a given property of the native soil and does not change with agricultural activities. Aggregation, however, can be improved or weakened through the timing of farm practices. Among the practices that destroy or degrade soil aggregates are: excessive tillage, tilling when the soil is too wet or too dry, using anhydrous ammonia (because it speeds the decomposition of organic matter), using excessive nitrogen fertilization, or using salty irrigation water or sodium-containing fertilizers, which results in the excessive buildup of sodium (Sullivan, 2002). It has been estimated that for every 1% of SOM content, the soil can hold 10.000-11.000 liters of plant-available water per ha of soil down to about 30 cm (Sullivan, 2002).

However, it has to be pointed out that local specificity plays an important role in determining the performance of a farming system: what is sustainable for one region may not be for another region or area (Smolik *et al*., 1995). So, more work has to be done to acquire knowledge about the comparative sustainability of different farming systems.

Adaptive measures to cope with climate change should treasure knowledge gained from organic farming. Extensive experimentation should be conducted to gain better understating of the complex interaction among farming practices, environmental characteristics and agroecosystem resilience.

E. The Potential for Organically Managed Farming Systems to Operate as a Carbon Sink and Contribute to GHGs Reduction

Annual fossil CO_2 emissions increased from an average of 6.4 Gt C (or 23.5 Gt CO_2) per year in the 1990s to 7.2 Gt C (or 26.4 $GtCO_2$) per year in 2000–2005. CO_2 emissions associated with land-use change are estimated to average 1.6 GtC (5.9 $GtCO_2$) per year over the 1990s, although these estimates have a large uncertainty (IPCC, 2007).

Agricultural activities (not including forest conversion) account for approximately 5% of anthropogenic emissions of CO_2 and the 10–12% of total global anthropogenic emissions of GHGs (5.1 to 6.1 Gt CO_2 eq. yr^{-1} in 2005), accounting for nearly all the anthropogenic methane and one to two thirds of all anthropogenic nitrous oxide emissions are due to agricultural activities (IPCC, 2000, 2007).

In 2008, in the United States, agricultural activities were responsible for about 7% of total U.S. GHGs emissions in 2008 (with livestock as major contributors) with an increase of 10% from 1998 to 2008 (U.S. EPA, 2010).

According to Smith *at al*. (2008) many agricultural practices can potentially mitigate GHG emissions, such as: improved cropland and grazing land management, restoration of degraded lands and cultivated organic soils; and point out that the current levels of GHG reduction are far below the technical potential of these agricultural practices. Smith *et al*. (2008) estimate that agriculture could offset, at full biophysical potential, about 20% of total global annual CO_2 emissions.

Some authors (Kern and Johnson, 1993; Schlesinger, 1999) report that converting large areas of U.S. cropland to conservation tillage (including no-till practices), could sequester all the CO_2 emitted from agricultural activities in the United States, and up to 1% of today's fossil fuel emissions 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^{-1}. This equals to a reduction of 5% to 15% of global CO_2 emissions.

In a 10-year systems trial in American Midwest, Grandy and Robertson (2007) found that compared to conventional agriculture, increases in soil C concentrations from 0 to 5 cm occurred with no-till (43%), low input (17%) and organic (24%) management. Soil carbon fixation is possible for conventional agriculture ranging from 8.9 gC m^{-2} y^{-1} (0.89 t ha^{-1} y^{-1}) in row crops to 31.6 gC m^{-2} y^{-1} (3.16 t ha^{-1} y^{-1}) in the early successional forage crops. Reduction in land use intensity increases soil C accumulation in soil aggregates. The authors argue that soil tillage is of key importance to determine soil C accumulation and suggest that there is high potential for carbon sequestration and offsetting atmospheric CO_2 increases by effective management of agriculture land.

Evidence from numerous long-term agroecosystem experiments indicates that returning residues to soil, rather than removing them, converts many soils from "sources" to "sinks" for atmospheric CO_2 (Rasmussen *et al*., 1998; Lal, 2004; Smith *et al.*, 2008).

Properly managed agriculture and SOM increase in cultivated soil play an important role in the storage of carbon, and this has been addressed by many authors (e.g., Janzen, 2004; Drinkwater *et al*., 1998; Stockdale *et al*., 2001; Pretty *et al*., 2002; Holland, 2004; Lal, 2004; Pimentel *et al.*, 2005; IPCC, 2007; Smith *et al.*, 2008). This carbon can be stored in soil by SOM and by aboveground biomass through processes such as adopting rotations with cover crops and green manures to increase SOM, agroforestry, and conservation-tillage systems. According to a review carried out by Pretty *et al*. (2002), carbon accumulated under improved management increased by more than 10 times, from 0.3 up to 3.5 tC ha^{-1} yr^{-1}.

Organic agriculture practices play an important role in enhancing carbon storage in soil in the form of SOM. Results from a 15-year study in the United States, where three district maize/soybean, two legume-based and one conventional agroecosystems 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}).

Both because there is a limit to how much carbon the soil can capture acting as a carbon sink and because fossil fuels are being used at a very rapid pace, conversion to organic agriculture only represents a temporary and partial solution to the problem of carbon dioxide emissions Foereid and Høgh-Jensen (2004) developed a computer model for organic agriculture acting as carbon sink, and simulations show a relatively fast increase in the first 50 years, by 10–40 g C m^{-2} y^{-1} on average; this increase would then level off, and after 100 years reach an almost stable level of sequestration.

Although organic agriculture may 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 by reducing overall energy consumption.

F. Soil Ecology, Biodiversity, and Its Effects on Pest Control

One hectare of high-quality soil contains an average of 1,300 kg of earthworms, 1,000 kg of arthropods, 3,000 kg of bacteria, 4,000 kg of fungi, and many other plants and animals (Pimentel *et al*., 1992; Lavelle and Spain, 2002). Transition to organic soil management can benefit soil biodiversity. In this context, it

should also be noted that SOM play an essential role in increasing soil biodiversity (Pimentel *et al*., 2006).

Enhancement of soil microbes and soil microfauna by organic inputs has been demonstrated in alternative farming systems across different climatic and soil conditions (Paoletti *et al*., 1995, 1998; Gunapala and Scow, 1998; Fließbach and Mäder, 2000; Hansen *et al.*, 2001; Mäder *et al*., 2002a; Marinari *et al.* 2006; Tu *et al*., 2006; Briar *et al*., 2007 Fließbach *et al*., 2007; Liu *et al.*, 2007; Birkhofer *et al*., 2008; Phelan, 2009).

Hansen *et al*. (2001), reviewing several studies on soil biology, found that organic farming is usually associated with a significantly higher level of biological activity, represented by bacteria, fungi, springtails, mites and earthworms, due to its versatile crop rotations, reduced applications of nutrients, and the ban on pesticides.

In a Swiss long-term experiment (Siegrist *et al*., 1998; Mäder *et al*., 2002a; Fließbach *et al*., 2007), soil ecological performance were greatly enhanced under biodynamic and organic management.

Microbial biomass and activity increased under organic management, root length colonized by mycorrhizae in organic farming systems was 40% higher than in conventional systems. Biomass and abundance of earthworms were from 30 to 320% higher in the organic plots as compared with conventional. Although the number of species of carabid beetles were not significantly higher in organic and biodynamic system compared to conventional (28–34 in biodynamic; 26–29 in organic and 22–26 in conventional), still some specialized and endangered species were reported to be present only in the two organic systems.

Concerning soil health, Briar *et al*. (2007) conclude that transition from conventional to organic farming can increase soil microbial biomass, N and populations of beneficial bacterivore nematodes while simultaneously reducing the populations of predominantly plant-parasitic nematodes. The authors also indicate that reducing tillage provides benefits for the development of a more mature soil food web.

In a seven-year experiment in Italy, Marinari *et al.* (2006) compared two adjacent farms, one organic and one conventional, and found that the fields under organic management showed significantly better soil nutritional and microbiological conditions; with an increased level of total nitrogen, nitrate and available phosphorus, and an increased microbial biomass content, and enzymatic activities.

Liu *et al*. (2007) report that in North Carolina microbial respiration in soils from organic farms was higher than that in low-input or conventional farms, indicating that microbial activity was greater in these soils, and that populations of fungi and thermophiles were significantly higher in soils from organic and low-input when compared to those of conventional fields.

Birkhofer *et al*. (2008) found that organic farming fosters microbial and faunal decomposers and this propagates into the aboveground system, sustaining a higher number of generalist predators, thereby increasing natural pest control. The authors, however, note that grain and straw yields were 23% higher in systems receiving mineral fertilizers and herbicides then the organic systems.

Soil management also seems to affect pest response. A number of studies report pest preferring plants which have been nurtured with synthetic fertilizer rather than those growing in organically managed soil (Phelan *et al*., 1995, 1996; Alyokhin *et al*., 2005; Hsu *et al*., 2009). This is explained by the "mineral balance hypothesis" (Phelan *et al*., 1996), which states that organic matter and microbial activity associated with organically managed soils allow to enhance nutrient balance in plants, which in turn can better respond to pest attack. Phelan and colleagues (Phelan *et al*., 1995; 1996; Phelan, 2009) report that under green house controlled experiments, females of European corn borer (*Ostrinia nubilalis*) were found to lay consistently fewer eggs in corn on organic soil than on conventional soil. Research on the effect of butterfly *Pieris rapae crucivora,* a cabbage pest, by Hsu *et al*. (2009) indicated that these butterflies preferred to lay eggs on foliage of synthetically fertilized plants (authors argue that proper organic fertilization can increase plant biomass production and may result lower pest incidence). Moreover, Alyokhin *et al*. (2005) reported that densities of Colorado potato beetle (*Leptinotarsa decemlineata*) were generally lower in plots receiving manure soil amendments in combination with reduced amounts of synthetic fertilizers compared to plots receiving full rates of synthetic fertilizers, but no manure.

A more complex relation between soil fertilization and crop pest has been found by Staley *et al*., (2010). The authors report that two aphid species showed different responses to fertilizers: the *Brassica* specialist *Brevicoryne brassicae* was more abundant on organically fertilized plants, while the generalist *Myzus persicae* had higher populations on synthetically fertilized plants. The diamondback moth *Plutella xylostella* (a crucifer specialist) was more abundant on synthetically fertilized plants and preferred to oviposit on these plants. The authors found also that glucosinolate concentrations were up to three times greater on plants grown in the organic treatments, while nitrogen content as maximized on plant foliage under higher or synthetic fertilizer treatments.

IV. BIODIVERSITY

Biodiversity refers to the number, variety and variability of living organisms in a given environment. It includes diversity within species, between species, and among ecosystems (Wilson, 1988; Gaston and Spicer, 2004; Koh *et al*., 2004; Chivian and Bernstein, 2008). The concept also covers how this diversity changes from one location to another and over time. Biodiversity assessment, such as the evaluation of the number of species in a given area, or the more affordable use of bioindicators, can help in monitoring certain aspects of biodiversity (Paoletti, 1999; Büchs, 2003; Duelli and Obrist, 2003; Paoletti *et al.*, 2007a), even if due attention should be paid to the comparison procedure (Gotelli and Colwell, 2001; Duelli and Obrist,

2003; Pocock and Jennings, 2007). Within the term biodiversity also fall the biodiversity of crops and reared animals and the management strategy of the farm itself (e.g., rotation pattern, intercropping) (Lampkin, 2002; Caporali *et al*., 2003; Noe *et al*., 2005; Norton *et al*., 2009)

The most dramatic ecological effect of agriculture expansion on biodiversity has been habitat destruction, which, along with soil erosion and the intensive use of agrochemicals (e.g., pesticides and fertilizers), has combined to threaten biodiversity (Paoletti and Pimentel, 1992; Pimentel *et al*., 1995; Krebs *et al*., 1999; Benton *et al*., 2003; Foley *et al*., 2005; Pimentel *et al*., 2006; Butler *et al*., 2007; Paoletti *et al.*, 2007b). According to Czech *et al*. (2000), in the United States agriculture has contributed to endangering biodiversity more than any other cause except urbanization.

Organic farming can offer a possible solution to halt, or reduce, biodiversity loss by a number of means such as preservation of ecological elements of the landscape, reduction in the use of harmful chemicals and alleviation of stress caused on soil ecology.

A. Organic Farming and Biodiversity

Whether organic agriculture enhances biodiversity has been a matter of research and debate for the last decades (Paoletti and Pimentel, 1992; Moreby *et al.*, 1994; Stockdale *et al*., 2001; Shepherd *et al*., 2003; Bengtsson *et al*., 2005; Fuller *et al.*, 2005; Hole *et al.*, 2005; Hyvönen, 2007; Norton *et al*., 2009).

Extensive analysis (e.g., Moreby *et al.*, 1994; Pfiffner and Niggli, 1996; Mäder *et al.*, 2002a; Caporali *et al*., 2003; Bengtsson *et al.*, 2005; Fuller *et al.*, 2005; Hole *et al.*, 2005; Roschewitz *et al.*,2005; Gabriel *et al.,* 2006, 2010; Clough *et al.*, 2007a; Hyvönen, 2007; Hawesa *at al.,* 2010), suggest that organic farming is generally associated with higher levels of biodiversity with regards to both flora and fauna.

A wide meta-analysis by Bengtsson *et al*. (2005) indicated that organic farming often has positive effects on species richness and abundance: 53 of the 63 studies analyzed (84%) showed higher species richness in organic agriculture systems, but a range of effects considering different organism groups and landscapes. Bengtsson *et al*. (2005) suggest that positive effects of organic farming on species richness can be expected in intensively managed agricultural landscapes, but not in small-scale landscapes comprising many other biotopes as well as agricultural fields. A review of the literature carried out by Hole *et al*. (2005) confirms the positive effect of organic farming on biodiversity, but authors point out that such benefits may be achieved also by conventional agriculture when carefully managed (a finding that seems supported also by other authors, e.g., Gibson *et al*., 2007), and indicate the need for long term, system-level studies of the biodiversity response to organic farming.

Comparing local weed species diversity in organic and conventional agriculture in agricultural areas in Germany, Roschewitz *et al*. (2005) found that weed biodiversity was influenced by both landscape complexity and farming system. The authors reported that local management (organic vs. conventional) and complexity of the surrounding landscape had an influence on alpha, beta and gamma diversities of weeds in 24 winter wheat fields. Species diversity under organic farming systems was clearly higher in simple landscapes, but conventional vegetation reached similar diversity levels when the surrounding landscape was richer because of the presence of refugia for weed populations. Roschewitz *et al*. (2005) argue that agri-environment schemes designed to preserve and enhance biodiversity should not only consider the management of single fields but also that of the surrounding landscape. Along similar lines, in Finland, Hyvönen *et al*. (2003) studied diversity and species composition of weed communities during spring in cereal fields cultivated by organic, conventional cereal and conventional dairy cropping, and concluded that organic cropping tends to promote weed species diversity at an early phase of cropping history, in particular for species susceptible to herbicides. The authors, however, argue that a change in species composition would require a longer period of organic cropping. In Scotland, Hawesa *at al.* (2010) found significantly more weeds in the seedbank and emerged weed flora of organic farms compared to either integrated or conventional farms and concluded that organic systems tend to support a greater density, species number and diversity of weeds compared to conventional management.

It has been demonstrated that when farming management is turned from conventional to organic, the weed populations can be restored to a state comparable to that before application of intensive cropping measures (Hyvönen and Salonen, 2002; Hyvönen, 2007). However, the recovery of the weeds is reported to differ between species, with species with a more rapid recovery being nitrophilous species that suffered from the application of herbicides, or species that were tolerant against herbicides. Perennial species favored by grasslands showed the slowest recovery. The authors point out that application of diverse crop rotations in organic cropping is the focal factor affecting species composition of weed communities.

Pfiffner *et al.* (2001) conducted a review of 44 investigations worldwide concerning the effects of organic and conventional farming on fauna, and reported organic farming as performing much better on both organism abundance and species diversity.

In Swiss trials (Pfiffner and Niggli, 1996; Mäder *et al.*, 2002a; Pfiffner and Luka, 2003), earthworms, carabids, epigeal spiders and other epigeal arthropods have been reported to be more abundant and with higher biodiversity in organic/biodynamic fields compared to conventional fields. They suggest the higher abundance might depend upon low-input and organic fertilization, more favorable plant biota protection management (especially weed management) and possibly upon closer interaction with semi-natural habitats.

Ekroos *et al*. (2010), comparing both weed and carabid beetles biodiversity, find that, in the case of weds, organic farming increased both insect-pollinated as well as overall weed species richness, whereas the proportion of insect-pollinated weed

species within the total species richness was unaffected by farming practices; on the other hand, in the case of carabid beetles a positive correlation with organic farming was less evident. Pfiffner and Niggli (1996) reports higher diversity and abundance of carabid beetles (90% greater) and other epigeic arthropods on organic plots of winter wheat than in conventional plots. Research carried out in North Eastern Italy in different types of orchards and vineyards found that arthropods, carabid species and earthworms were more abundant in organic than in conventional agroecosystems (Paoletti *et al*., 1995, 1998). Greater abundance of earthworms (up to more than 100%) and insects for organic farms has been reported also for Swiss farming system (Pfiffner and Mäder, 1997; Pfiffner and Luka, 2007).

In the largest and most comprehensive study of organic farming in the UK to date, Fuller *et al*. (2005) shows that organic farms provide greater benefits for a range of wildlife (including wild flowers, beetles, spiders, birds and bats) than their conventional counterparts. Fuller *et al*., (2005) found that organic fields were estimated to hold 68–105% more plant species and 74–153% greater abundance of weeds (measured as cover) than nonorganic fields support, 5–48% more spiders in preharvest crops, 16–62% more birds in the first winter and 6–75% more bats (see also Wickramasinghe *et al.,* 2004, who have found that organic farming is beneficial to bats, both through provision of more structured habitats and higher abundance of insect prey). These studies indicate that organic farming systems provide greater potential for biodiversity than their conventional counterparts, as a result of greater variability in habitats and more wildlife-friendly management practices, which results in real biodiversity benefits, particularly for plants. Plants indeed showed far more consistent and pronounced responses to the use of organic systems when compared to other taxa, as reported also by Bengtsson *et al*. (2005).

In the case of other taxa, Fuller *et al*. (2005) report that even where significant differences were detected, the results showed high variability and wide confidence intervals. Compared to the review by Bengtsson *et al*. (2005), Fuller *et al*. (2005) in their meta-analysis find that predatory invertebrates showed a significant response to agricultural practices only infrequently.

Results from Swedish research on butterfly species diversity in organic and conventional farms (Rundlöf and Smith, 2006; Rundlöf *et al*., 2008) indicate that both organic farming and landscape heterogeneity significantly increased butterfly species richness and abundance. Authors report also that there was a significant interaction between farming practice and landscape heterogeneity, and organic farming significantly increased butterfly species richness and abundance only in homogeneous rather than heterogeneous landscapes.

A previous Swedish study (Weibull *et al*., 2003) did not find differences when comparing the biodiversity and abundance of plants, butterflies, rove beetles and spiders in organic and conventional farms, while carabids richness was higher in conventional farms. The authors argued that species richness was higher on farms with a heterogeneous landscape, while farming practice was of relatively less importance in relation to landscape features for species richness.

A review of literature on carabid beetles in organic and conventional farming system in Germany and Switzerland by Döring and Kromp (2003) found that in most cases species richness was higher in the organically than in the conventionally managed fields.

No difference for carabids biodiversity were instead reported by the USDA Farming Systems Project in Maryland, by Clark *et al*. (2006) in organic, no-till, and chisel-till cropping systems.

According to van Elsen (2000), economic pressure leads to an improvement in mechanical weed control and undersowing, so that supporting and developing a diverse arable field flora cannot be done automatically just by converting to organic farming. Rather, an integration with the guiding vision of organic agriculture is needed, and measures to support the richness of species of arable field plants in organic fields have to be developed.

B. Biodiversity and Landscape

An increasing body of evidence indicates that landscape heterogeneity is a key factor in promoting biodiversity in the agricultural landscape (Benton *et al.*, 2003; Purtauf *et al*., 2005; Schmidt *et al*., 2005; Tscharntke *et al*., 2005; Gabriel *et al.,* 2006, 2010; Rundlöf and Smith, 2006; Clough *et al.*, 2007b; Norton *et al*., 2009). A mosaic landscape may support a larger number of species in a given area, simply because the landscape contains a larger number of habitats. Organic farming system produced greater field and farm complexity than farms employing a nonorganic system (Gabriel *et al.,* 2006, 2010; Clough *et al.*, 2007b; Norton *et al*., 2009). In Germany, Gabriel *et al.* (2006, 2010) found that plant species in wheat organic farming made the greatest contribution to total species richness at the meso (among fields) and macro (among regions) scale due to environmental heterogeneity. Rundlöf and Smith (2006) argue that organic farming, with its exclusion of pesticides and longer crop rotation, may, on a landscape scale, increase habitat heterogeneity and biodiversity.

Some scholars argue that because many organic farms are often isolated units, embedded in nonorganic farmland managed with conventional levels of pesticide and fertilizer inputs, offering a relatively low levels of habitat heterogeneity, this may reduce the benefits offered by organic farming as well as by species colonization. In these cases, organic farming probably offer insufficient resources to affect population sizes of species with large spatial needs, such as birds (Bosshard *et al*., 2009; Brittain *et al*., 2010).

Concerning invertebrates, agricultural landscapes with organic crops have overall been reported to support higher biodiversity for pollinator (Holzschuh *et al*., 2008), butterfly (Rundlöf and Smith, 2006), carabid beetle (Purtauf *et al*., 2005), spiders (Fuller *et al*., 2005; Schmidt *et al.*, 2005), and a number of invertebrates taxa (Benton *et al.*, 2003; Bengtsson *et al*., 2005; Clough *et al*., 2007). It has to be pointed out that the extent of

non-crop habitat in the vicinity of organic farms (usually larger than for conventional farms) is likely to be beneficial for biodiversity (Holzschuh *et al*., 2007; Norton *et al*., 2009). Holzschuh *et al.* (2007), for instance, found that landscape heterogeneity and the availability of semi-natural nesting habitats resulted in higher bee diversity on farmland.

It would appear that the extension of organic farming is a potential means of reestablishing heterogeneity of farmland habitats, and thereby enhancing farmland biodiversity. However, the total area of organic farmland relative to nonorganic is generally small (a few points percentage of the total agricultural area per country). Strategies aimed at increasing both the total extent of organic farming and the size and contiguity of individual organic farms could help to restore biodiversity in agricultural landscapes (Fuller *et al*., 2005; Tscharntke *et al*., 2005; Bosshard *et al.*, 2009). This strategy is supported also by other authors. Benton *et al.* (2003) for instance, argue that, rather than concentrating on particular farming practices, promoting heterogeneity widely across agricultural systems should be a universal management objective.

Given the body of evidence accumulated so far, it is clear that measures to preserve and enhance biodiversity in agroecosystems should be both landscape and farm specific (e.g., Paoletti, 1999; Thies and Tscharntke, 1999; Hole *et al*., 2005; Pimentel *et al*., 2005; Roschewitz *et al*., 2005; Tscharntke *et al*., 2005; Gabriel *et al.,* 2006, 2010; Rundlöf and Smith, 2006; Holzschuh *et al*., 2008; Norton *et al*., 2009). Unfortunately, it is difficult to provide reliable recommendations concerning agricultural land management in order to enhance biodiversity and ecosystem services, because there is still little knowledge about the relation among agricultural land management, both at farm and at landscape level, and ecosystem services. (Tscharntke *et al*., 2005; Gabriel *et al.,* 2006, 2010).

C. Biodiversity and Pest Control

One key feature of agricultural intensification has been the increasing specialization in the production process, resulting in reduction in the number of crop and livestock species, leading to monoculture and intensive farming (Zhu *et al.*, 2000; Matson *et al*., 1997; Tscharntke *et al*., 2005). On the other hand, it has been demonstrated that increasing crop genetic diversity can play an important role in pest management and in controlling crop disease, as well as enhance pollination services and soil processes (Zhu *et al.,* 2000; Barberi, 2002; Hajjar *et al*., 2008). Zhu *et al.* (2000), for instance, demonstrated that crop heterogeneity is a possible way to solve the problem of vulnerability of monoculture crops to disease. Barberi (2002) argues that weed management should be tackled on a long time frame and needs deep integration with the other cultural practices, so as to optimize whole system control.

Agriculture intensification results also in a dramatic simplification of landscape composition and in a sharp decline of biodiversity. This also affected the functioning of natural pest control, as natural habitats provide shelter for a broad spectrum of natural species that operate as pest control for all crops (Pimentel *et al*., 1992; 1997; Kruess and Tscharntke, 1994; Pimentel, 1997; Thies and Tscharntke, 1999; Barbosa, 2003; Altieri and Nicholls, 2004; Perfecto *et al*., 2004; Bianchi *et al*., 2006; Crowder *et al*., 2010).

Preserving landscape-ecological structures (e.g., hedgerows, herbaceous strips, woodlot) means also preserving their function as a haven for beneficial organisms that can provide useful services to agriculture. On the contrary, reducing ecological structures and causing habitat fragmentation results in a significant reduction in local biodiversity and its impact in the biological control of pests (Kruess and Tscharntke, 1994; Sommaggio *et al*., 1995; Paoletti *et al.*, 1997; Thies and Tscharntke, 1999; Letourneau and Goldstein, 2001; Thies *et al.*, 2003, 2005; Bianchi *et al*., 2006; Gardiner *et al*., 2009).

Letourneau and Bothwell (2008) argue that few studies have measured biodiversity effects on pest control and yield on organic farms compared to conventional farms, while relevant studies suggest that an increase in the diversity of insect predators and parasitoids can have both positive and negative effects on prey consumption rates. As mentioned earlier in this paper, Briar *et al*. (2007) reported the positive role of the transition from conventional to organic farming in increasing populations of beneficial bacterivore nematodes while reducing plant-parasitic nematodes.

Perfecto *et al*. (2004) found that in coffee farms in Chiapas, Mexico, birds could potentially reduce pest outbreak in farms with higher floristic diversity, thus providing partial evidence in support of the "insurance hypothesis." In organic cereal fields in Germany, Westerman *et al*. (2003) found that seed predation by birds contributes substantially to the containment of weed population growth.

Other experiments proved the role of vegetation and bird presence in reducing pest outbreaks. Mols and Visser (2002, 2007), for instance, found that big tit (*Parus major* L.), a European cavity-nesting bird, reduces the abundance of harmful caterpillars in apple orchards by as much as 50 to 99%. In the Netherlands, the foraging of *P. major* increased apple yields by 4.7 to 7.8 kg per tree.

Although some studies do not find a correlation between landscape complexity and parasitoid diversity (e.g., Menalled *et al*., 1999), most of them do confirm the importance of ecological structures for harbouring beneficial organisms. Research in Italy found that hedgerows in organic farming can improve consistently the number and abundance of invertebrates and can host important key species of predators and parasitoids that can provide a natural pest control for crops (Paoletti and Lorenzoni, 1989; Sommaggio *et al*., 1995; Paoletti *et al*., 1997). In an extensive experiment to assess the effectiveness of natural pest control provided to soybean by natural pest predators, 26 replicate fields were set across Michigan, Wisconsin, Iowa, and Minnesota over two years (2005–2006) (Gardiner *et al*., 2009). The authors found that the abundance of Coccinellidae was related to landscape composition, with beetles being more abundant in landscapes with an abundance of forest and grassland compared

with landscapes dominated by agricultural crops. Landscape diversity and composition at a scale of 1.5 km surrounding the focal field explained the greatest proportion of variation in biological control service index (based on relative suppression of aphid populations and on Coccinellidae abundance). The authors conclude that management aimed at maintaining or enhancing landscape diversity has the potential to stabilize or increase biocontrol services.

Bianchi *et al*. (2006) reach the same conclusions. They find that enhanced natural enemy activity showed correlation with presence of herbaceous habitats such fallows and field margins (80% of cases), and also with presence of wooded habitats (71%), and of landscape patchiness (70%). The authors conclude that all these landscape characteristics are equally important in enhancing natural enemy populations, and claim that diversified landscapes hold most potential for the conservation of biodiversity and perform a pest control function.

It is often assumed that if the reduction in agrochemicals on organic farms allows the conservation of biodiversity, it on the other hand must have some cost in terms of increased pest damage. In an experiment in tomato farms in California, Letourneau and Goldstein (2001) tested such a claim. The authors found no evidence of increased crop loss when synthetic insecticides are withdrawn. The authors stress the importance of large-scale on-farm comparisons for testing hypotheses about the sustainability of agroecosystem management schemes and their effects on crop productivity and associated biodiversity.

Recently, Crowder *et al*. (2010) showed that such insecticides disrupt the communities of pest natural enemies, reducing the effectiveness of pest control. Authors claim that organic farming methods can mitigate this ecological damage by promoting evenness among natural enemies, implying that ecosystem functional rejuvenation requires restoration of species evenness, rather than just richness, and that organic farming can offer a means of reestablishing functional evenness to ecosystems. Bahlai *et al.* (2011), however, point out that organic pesticides may not represent always the best solution to mitigate environmental risk.

It has to be pointed out that biodiversity conservation, by retaining local food web complexity can also represent an effective management strategy against the spread of invasive species that often act as pests in new environments (Kennedy *et al.*, 2002). This may help to avoid the drawback from using exotic natural enemies to fight novel invasive species, as species introduced for biocontrol can act as invasive species in their own right (Thomas and Reid, 2007).

V. ENERGY USE AND GHGs EMISSION

A. Energy Efficiency

Organic farming has been reported to provide a better ratio of energy input/output (Table 2). (For further figures see also the review by Lynch *et al.*, 2011)

The main reasons for higher efficiency in the case of organic farming are: (1) lack of input of synthetic N-fertilizers (which require 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; Stockdale *et al*., 2001, Haas *et al*., 2001; FAO, 2002; Lampkin, 2002; Hoeppner *et al*., 2006; Kasperczyk and Knickel, 2006; Küstermann *et al.,* 2008; Lynch *et al.*, 2011). According to estimates carried out in a study conducted by the Danish government (Hansen *et al*., 2001), upon 100% conversion to organic agriculture a 9–51% reduction in total energy use would ensue (the rate of reduction depending on the level of imported feeds and the numbers of animals reared).

However, when calculating energy input in terms of physical output units, a reduced advantage in employing organic systems was observed (Cormack, 2000; Stockdale *et al*., 2001). On average, yield from arable crops is reported to be 20% to 40% lower in organic systems compared to conventional systems, whereas the yield for horticultural crops could be as low as 50% that of conventional; grass and forage production is reported between 0 and 30% lower for organic systems (Cormack, 2000; Stockdale *et al*., 2001; Mäder *et al.*, 2002a, 2002b; Cavigelli *et al*., 2007; Kirchmann *et al*., 2007; Küstermann *et al.*, 2008).

Dalgaard *et al*. (2001) argue that the energy efficiency, calculated as the yield divided by the energy use (MJ ha^{-1}), was generally higher in the organic system than in the conventional system, but the yields were also lower. This meant that conventional crop production had the highest net energy production, whereas organic crop production had the highest energy efficiency.

In industrial societies, energy efficiency *per se* may not be the goal. Increasing productivity per hour of labor is in fact what modern society aims at, and this may lead us in the opposite direction (decreasing overall energy efficiency) (Giampietro, 2004). This 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 $ha^{-1}yr^{-1}$(24.5 in output and 7 in input), while traditional just 6.3 million kcal $ha^{-1}yr^{-1}$ (7 million in output and 0.6 million in input) (Pimentel, 1989).

On the other hand, some studies have found organic production comparable to that of conventional systems (Clark *et al*., 1999; Pimentel *et al*., 2005). Clark *et al*. (1999) argue that organic and low-input tomato systems can produce yields similar to those of conventional systems but that factors limiting yield may be more difficult to manage: N availability in the case of organic systems and water availability in that of conventionally managed systems. In the Rodale long-term study (Pimentel *et al*., 2005) organic performance is comparable to conventional

TABLE 2
Comparison of energy efficiency (input/output) per unit of production of organic as percent of conventional farming systems.

Farming System	Reference	Energy Efficiency organic 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 in 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 crop systems in Iran	Zarea *et al.* (2000) (in FAO, 2002)	+81
Rotations of different crop 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
Apricot in Turkey	Gündomuþ (2006)	+53
Olive in Spain	Guzmán and Alonso (2008)	+50
Crop rotations	Küstermann *et al.* (2008)	+9
Results from Long-Term Agroecosystem Experiments		
Apples in 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
Organic vs. conv. with tillage	Gelfand *et al.* (2010)	+10
Organic vs. conv. no tillage	Gelfand *et al.* (2010)	−30

performance with respect to key agronomic indicators (Table 3).

As previously mentioned, it has to be pointed out that under drought conditions organic systems produce higher yields than comparable crops managed conventionally, up to 70–90% (Lockeretz *et al*., 1981; Stanhill, 1990; Smolik *et al*., 1995; Lotter *et al*., 2003; Pimentel *et al*., 2005).

It appears that the energetic performances of different farming systems depend on the crops cultured and specific farm characteristics (e.g., soil, climate). 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 explained by different management techniques and their improvement in the last 20 years.

B. GHGs Emission

Agricultural contributions to CO_2 emissions come from consumption of energy in the form of oil and natural gas, both

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, 2006, modified).

Crop	Technology	Yield (t ha^{-1})	Labor (hrs ha^{-1})	Energy (kcal x 10^6)	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.

directly (e.g., field work, machinery) and indirectly (e.g., production and transport of fertilizers and pesticides). Changes in soil ecology can also result in carbon release 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). On the other hand, it is 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). This technology is, however, not limited to organic management.

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 for the lower CO_2 emissions per unit of products in organic agriculture.

Haas *et al*. (2001) conducted a Life Cycle Assessment of the environmental impacts of 18 grassland farms in three different farming intensities (intensive, extensified, and organic) in southern Germany. They found that extensified and organic farms reduce energy consumption and Global Warming Potential (GWP). The authors found that the area-related GWP decreases for intensive (9.4 t CO_2 eq. ha^{-1}), extensified (7.0 t CO_2 eq. ha^{-1}) and organic farms (6.3 t CO_2 ha^{-1}), accordingly. With regards to product-related energy use, extensified farms (1.0 t CO_2 eq. ha^{-1}) cause the lowest GWP, whereas intensified and organic farms (1.3 t CO_2 eq. ha^{-1}) produce the same emissions. Lower CO_2^- and N_2O^- emissions of organic farms are compensated by a higher emission of CH_4 per unit of produced milk, because of lower milk yields.

Comparing the performances of single crops can produce very different results from those obtained when comparing the whole cropping system within which that specific crop is found. Küstermann *et al*. (2008), for instance, report that GHGs per ha for winter wheat are comparable between organic and conventional system. On a harvested biomass basis, lower yields in organic farming involved higher emissions (496 kg CO_2 eq. Mg^{-1} for the organic system and 355 kg CO_2 eq. Mg^{-1} for the conventional), when all products relating to the whole crop rotation are considered, organic management is shown to result in lower emission (263 kg CO_2 eq. Mg^{-1}, for the organic system against 376 kg CO_2 eq. Mg^{-1} for the conventional system) (Table 4).

Modeling of a transition to organic production in Canada, Pelletier *et al*. (2008) found that a total transition of Canadian canola, corn, soybean and wheat production to organic management may reduce the overall national energy consumption by 0.8%, GHGs emissions by 0.6%, and acidifying emissions (from N and S compounds) by 1%. The authors argue that although organic farming systems have a slightly higher fuel-related energy consumption, still their average total energy demand has been estimated at about 40% that of conventional management, mainly due to the use of synthetic fertilizer and pesticide (quite costly in terms of energy demand) in conventional systems. Such calculations, however, do not account for organic compost shipments over long distance.

Wood *et al.* (2006) carried out a comprehensive environmental impacts analysis of Australian agriculture, and argue that organic production has smaller indirect impacts than conventional production, and that a transition to organic farming could be a viable way of reducing energy use and GHG emissions, while maintaining employment and economic benefits. In their review, Lynch *et al*. (2011) fond that organic systems has gnerally lower GHGs emission per ha but the results are variable on a per unit of product basis.

C. Integrating Animal Husbandry

In organic farming, animal husbandry is carried out taking into account ethical concerns regarding the well being of the animals, and therefore, amongst other practices, it promotes natural behavior of cows by having them spend most of the grazing period outdoors, it limits the use of drugs and endorses the use of feed coming from crops where the use of synthetic fertilizers and pesticides is forbidden (Lund, 2006). This translates to better consumer health, having meat without an extra supply of (synthetic) hormones and traces of antibiotics.

According to some authors (Subak, 1999; Cederberg and Stadig, 2003; Koneswaran and Nierenberg, 2008a, 2008b)

TABLE 4
CO_2 emissions for some productions (data from Küstermann *et al.,* 2008).

	GHGs emission per ha (kg CO_2 eq. ha^{-1})			GHGs emission per production unit (kg CO_2 eq. t^{-1})		
Study	Conv.	Organic	Org. as % of conv.	Conv.	Organic	Org. as % of conv.
Winter wheat	2,333	1,669	71	355	496	140
Similar crop rotation	2,717	887	32	376	263	70

organic animal husbandry has the potential to reduce GHG emissions and sequester carbon through better pasture management. Raising cattle for beef organically on grass, in contrast to fattening confined cattle on concentrated feed, may emit 40% less GHGs and consume 85% less energy than conventionally produced beef. According to Williams *et al*. (2006), most organic animal production reduces primary energy use by 15% to 40%, with the exception of organic poultry meat and egg production, which increase energy use by 30% and 15% respectively.

How to develop appropriate analytical methods to assess the sustainability of organic meat and milk production is, however, still work in progress and a matter of debate (e.g., De Boer, 2003; Avery and Avery, 2008; Koneswaran and Nierenberg, 2008a; 2008b; Müller-Lindenlauf *et al*., 2010).

A study of German dairies by Haas *et al*. (2001) reports an energy use per unit of milk for organic agriculture that is less than half of that of conventional farming, and less than one-third per unit of land. For instance, De Boer (2003), argued that at present we cannot directly compare results of different LCA studies. The author noted that, for example, absolute GWP differs largely among studies because of differences in allocation or normative values used with respect to CH_4 and N_2O emission. Lacking a standardized protocol for LCA, De Boer (2003, p. 76) stated that "conventional and organic production systems can be compared only within a case study." Avery and Avery (2008) of the Huston Institute (a think tank based in Washington D.C.), challenged the data by Koneswaran and Nierenberg (2008a), whose figures indicated organic animal production systems performing better than conventional, claiming that the authors were comparing highly different environmental and cultural contexts (Sweden and Japan), and citing different studies to support different conclusion. Koneswaran and Nierenberg (2008a; 2008b), on the other hand, replied that the LCA cited by Avery and Avery (2008) are still misleading and, in some cases, wrongly quoted. Further to the LCA issue, De Boer (2003), argued also that experimental farms, from which comparison between organic and conventional animal production are made, do not necessarily represent corresponding production systems. Müller-Lindenlauf *et al*. (2010), called for the adoption of a more complex approach, arguing that focussing only on the classical environmental impact categories (e.g. energy efficiency, GWP) may lead to different results than a system approach that includes a broader range of relevant impacts and ecological benefits. However, there were slightly higher methane emissions per unit of organically produced milk, and the authors estimated that the final GWP of the two farming systems was similar (Tables 5a and 5b). Most LCA undertaken thus far report that organic management results in a bit less or equal footprints as compared to conventional. While outcomes rate organic management positively on a per hectare basis, performance per unit of production is less positive as organic management tends to yield less than conventional.

A German study based on a multicriterial assessment of milk production of organic and conventional farms (Müller-Lindenlauf *et al.,* 2010), concludes that organic farming tends to have less negative environmental effects than conventional farming. Results are, however, not neat. The authors found that intensive farm types tend to be advantageous in global categories such as climate impact and land demand. On the other hand, low-input farm types have significant advantages with regards to ammonia emissions, animal welfare and milk quality. The authors argue that carrying on an environmental impact assessment analyzing only a few indicators, e.g., GHGs emission and energy consumption, leads to different conclusions than an overall analysis taking into account a large number of regional and local factors. When considering land demand Müller-Lindenlauf *et al.* (2010) report that arable land demand (ha/1000 kg milk) was 0.07 for organic grasslands vs. 0.1 for conventional grasslands, and 0.03 for organic mix farm vs. 0.1 for conventional mix farm. That means that organic milk production was 3 to 10 times less dependent on arable land. Even if organic management resulted slightly higher on the overall land

TABLE 5a
Energy use and carbon emission in milk production in organic and conventional systems.

	Energy Consumption (GJ ha^{-1})			Energy Consumption (GJ t^{-1})		
Study	Conv.	Organic	Org. as % of conv.	Conv.	Organic	Org. as % of conv.
Cederberg and Mattsson (1998)	22.2	17.2	77	2.85	2.41	85
Refsgaard *et al.* (1998)	–	–	–	3.34	2.16/2.88	75/87
Cederberg and Mattsson (1998) in Haas *et al.* (2001)	–	–	–	2.85	2.4	92
Haas *et al.* (1995) in Haas *et al.* (2001)	19.4	6.8	35	–	–	–
Haas *et al.* (2001)	19.1	5.9	31	2.7	1.2	46
Thomassen *et al.* (2008)*				4.4	2.17	51
Müller-Lindenlauf *et al.* (2010) – Grassland	–	–	–	1.52	1.2	79
Müller-Lindenlauf *et al.* (2010) – Mix farm	–	–	–	1.17	1.32	113

(*) including indirect costs.

TABLE 5b
Energy use and carbon emission in milk production in organic and conventional systems.

	CO_2 Emission (kg CO_2 ha^{-1})			CO_2 Emission per Production Unit (kg CO_2 t^{-1})		
Study	Conv.	Organic	Org. as % of conv.	Conv.	Organic	Org. as % of conv.
Haas *et al.* (2001)	9,400	6,300	67	1,280[a]	428[a]	33
Haas *et al.* (2001)	–	–	–	1,300[b]	1,300[b]	0
Thomassen *et al.* (2008)*	–	–	–	1,400	1,500	107
Müller-Lindenlauf *et al.* (2010)–Grassland	–	–	–	1,036	1,172	113
Müller-Lindenlauf *et al.* (2010)–Mix farm	–	–	–	917	1,082	118

[a]considering only CO_2 emission; [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.
(*) including indirect costs.

demand (0.31 and 0.28 for organic vs. 0.27 and 0.22 for conventional), still the impact of organic farming on soil (e.g., soil loss, SOM, biodiversity) can be considered lower than that of conventional farming. Again, neither chemical residues in milk nor pesticide use in crops production were taken into consideration as sustainability indicators (and in some contexts pesticide use is indeed a cause of concern). The points raised should not be taken as criticism, as the work just described can be considered a nice and welcomed attempt to adopt a multicriterial approach in order to account for key indicators in a comprehensive farming system analysis. Our aim is to illustrate the complex nature of farming system analysis when attempting a comparison between different systems and the assessment of what is "the best."

In a review comparing milk production performance of organic and conventional systems, De Boer (2003) claims that few exact figures are available, especially on the amount of NO_2 and CH_4 emitted from dairy cattle production, and concludes that, firstly, the potential environmental impact of conventional and organic milk production is based largely on comparison of experimental farms, which do not necessarily represent the corresponding production systems Secondly, he suggests that different indicators provide different levels of performance; for instance, CH_4 emission appears higher in organic systems, while eutrophication potential per tonne of milk and per ha appears lower for organic milk production than for conventional. Thirdly the author argues that organic milk production potentially reduces leaching of NO_3^- and PO_4^-, due to lower fertilizer application rates.

VI. CONSTRAINTS TO THE ADOPTION OF ORGANIC AGRICULTURE

A. Feasibility

The benefits associated with the adoption of organic farming practices have been questioned by many authors to different degrees. Some authors claim that organic farming is an ideology rather than a scientific approach to agriculture (e.g., Kirchmann and Thorvaldsson, 2000; Rigby and Càceres, 2001; Trewavas, 2001, 2004; Edwards-Jones and Howells, 2001; De Gregori, 2003). Others express a milder form of criticism based on the concern that not all organic agriculture strategies can be applied globally and without many local adjustments, and because of this lack of coherence, they suggest that this approach may actually lead to a worsening of agricultural problems (e.g., Tilman *et al*., 2002; Elliot and Mumford, 2002; Wu and Sardo, 2010).

Some authors (e.g., Elliot and Mumford, 2002) suggest the adoption of integrated farming, rather than upholding solely organic practices, which they find more harmful than conventional farming, for instance in the case of pest control technologies.

B. Labor Productivity

When assessing the socioeconomic sustainability of farming enterprises, labor productivity 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 labor input (FAO, 2002). Little data exists for pig and poultry farms. 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, 2006).

In order to gain insight into 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; Gomiero *et al*., 2006). Data on energy efficiency cannot be detached from the "metabolism" of the social system where agriculture is performed. High energy efficiency may imply low total energy output that, for a large society with limited land, may not be a sustainable option, menacing food supply for urban

populations. With the current emphasis on promoting a green economy and paying farmers for environmental services, organic agriculture offers great potential to generate green jobs and revitalize rural areas. We warn, however, about looking at organic agriculture as a mean to produce biofuels (Giampietro and Ulgiati, 2005; Pimentel and Patzek, 2005; Giampietro and Mayumi, 2009; Gomiero *et al*., 2010).

C. Economic Performance

Comparing organic and conventional system is still not an easy task because authors often adopt quite different methodologies, and different geographical areas (e.g., developed and developing countries) have distinctive characteristics that should be properly taken into consideration (Nemes, 2009). Although yields in organic systems tend to be lower, input costs are usually lower. A number of studies report no major revenue difference for organic farming compared to conventional (e.g., Drinkwater *et al*., 1998; Delate *et al*. 2003; Pacini *et al.,* 2003; Mahoney *et al*., 2004; Pimentel *et al.,* 2005, for a comprehensive review of the topic see Nemes, 2009).

According to the U.S. Department of Agriculture (USDA, 2010a; Bowman, 2010), data from the organic farming census reveal that the 14,540 organic farms included in the census had an estimated average net income (total sales less expenses) of $20,249 per farm per year, a figure higher than the figure in which all farm types were included.

This has been reported also in some broad research conducted in developing countries. For instance, Eyhorn *et al*. (2007) found that in India the average gross margins from organic cotton fields were 30–40% higher than in conventional fields, due to 10–20% lower total production costs and a 20% organic price premium. Authors argue that although the crops grown in rotation with cotton were sold without premium, organic farms achieved all the same 10–20% higher incomes from agricultural activity.

Other studies, however, indicate that the impact of organic price premiums is large, and sometimes needed to match conventionally generated income and compensate for lower yields (e.g., Reganold *et al.*, 2001; Pacini *et al.,* 2003; Chavas *et al*., 2009; Nemes, 2009). Recent analysis for southern Wisconsin (USA) by Chavas *et al.* (2009) shows that, under the market scenarios that prevailed between 1993 and 2006, intensive rotational grazing and organic grain and forage systems were the most profitable systems. On, highly productive land organically grown corn resulted more profitable than continuous corn cropping. Once the premium was taken into account, organic farming resulted more profitable in all systems. Results for Low External Input (LEI) agriculture in the United States (Liebman *et al*., 2008) shows that corn and soybean yields in LEI systems can be sustained at levels that match or exceed levels obtained from conventional systems. Scenario analysis by Lohr and Park (2007) indicates that economic gains will be realized as farm size increases, creating pressure on organic farmers to expand operations. Protecting small organic farms is likely to become a policy issue in the near future.

D. Environmental Services of Organic Agriculture

Economic benefits from agriculture management cannot be limited to yield or commodities production, or account only for farm investment and revenue. For instance, issues such as energy efficiency and GHGs emissions, preserving water supply, biodiversity and landscape preservation and reduction in the use of agrochemicals are usually not assessed when conducting farming cost-benefit analyses. Still they play a key role for the long term sustainability of our support system and our environment, even if they have to be addressed on a broader spatial and temporal scale (Paoletti and Pimentel, 1992; Pimentel *et al.*, 1997; Tilman *et al*., 2001, 2002; Pretty *et al.*, 2003; FAO, 2004; Foley *et al.*, 2005; Millennium Ecosystem Assessment, 2005a; 2005b; Molden, 2007; Bosshard *et al*., 2009; Vitousek, *et al*., 2009).

It should be noted that organic agriculture provides many beneficial "by-products" both for the environment (e.g., conservation of soil fertility, CO_2 storage, fossil fuel reduction, preserving biodiversity) and for people (e.g., eliminating the use of agrochemicals such as synthetic fertilizers and pesticides, preserving landscape). We wish to stress that preserving or increasing soil organic matter content has to do not only with a farm long-term sustainability (and benefit), but, and maybe most importantly, with preserving a country's long term food security, guaranteeing that it can overcome and recover from possible future climate extremes.

In this sense it is important to get a deeper understanding of the nature of agroecosystems: they are embedded in complex ecological networks, characterized by nonlinearity and stochasticity. Theoretical and empirical research reveals that ecological systems persist and generate ecosystem services as a result of complex interacting components (Ehrlich and Ehrlich, 1981; Paoletti and Pimentel, 1992; Cliff, 1997; Pimentel *et al*., 1997; 2006; Loreau *et al*., 2002; Luck *et al*., 2009; Vandermeer *et al*., 2010). Benefits from insect services in the United States, for instance, are valued at $57 billion per year (Losey and Vaughan, 2006). But insect do not live in a vacuum, they are constrained by the environment-landscape characteristics. Eventually, benefits provided by insects depend on how we decide to manage the environment in which they may find their living from which they depend on. So, in order to fully benefit from ecosystems environmental services, we should manage our environmental at a broader scale than that of the single farm.

At the same time, economic analysis should take full account ("internalization") of the economic impact of conventional agriculture, addressing the issue of its long term sustainability (Pimentel *at al.*, 1995, 1997; Pretty *et al*., 2000, 2003; Buttel, 2003).

E. Organic Farming and Food Security

According to some authors organic agriculture can be a promising approach to sustain food security while decreasing the environmental impact of agriculture, especially in some

developing countries (Pretty and Hine, 2001; Altieri, 2002; FAO, 2002, 2008; Pretty, 2002; van Veluw, 2006; Niggli *et al*., 2007, 2008; El-Hage Scialabba, 2007; Badgley *et al*., 2008; El-Hage Scialabba and Müller-Lindenlauf, 2010). In low input systems, and especially in arid and semi-arid areas where most of the food-insecure people live, organic systems are reported to greatly improve yields (Pretty and Hine, 2001; Pretty, 2002). Although for perennial cropping, such as coffee or banana, significant yield reductions are reported, under appropriate agroforestry system, the lower yields for the main crop are compensated by producing other foodstuff and goods (El-Hage Scialabba and Müller-Lindenlauf, 2010).

Some authors (e.g., Pretty and Hine, 2001; FAO, 2002, 2008; Halberg *et al*., 2006; Badgley and Perfecto, 2007; Badgley *et al*., 2007; El-Hage Scialabba, 2007; Niggli *et al.,* 2007, 2008) argue that organic agriculture could benefit developing countries because organic practices contribute considerably to increasing soil stability and resilience, an important factor in food supply stability, and also save water, another critical resource in many areas. The authors claim that the productivity of organic compared to conventional farming depends strongly on soil and climate conditions as well as on choice of crops being compared, and under less favorable soil conditions, organically managed crop yields equal those from conventional agriculture. Recent models of a hypothetical global food supply grown organically (Badgley, *et al*., 2007; Halberg, *et al*., 2006) indicates that organic agriculture could produce enough food on a global *per capita* basis for the current world population.

In their review, Badgley *et al*. (2007) compared yields of organic versus conventional or low-intensive food production for a global dataset of 293 examples and estimated the average yield ratio (organic vs. nonorganic) of different food categories for the developed and the developing world, and found that for most food categories the average yield ratio was slightly <1.0 for studies in the developed world and >1.0 for studies in the developing world. The authors found also that in developed countries average yield losses under organic management ranged from 0 to 20% (Badgley *et al*., 2007). Pretty and Hine (2001) surveyed 208 projects in developing tropical countries in which contemporary organic practices were introduced, and found that average yield increased by 5–10% in irrigated crops, and by 50–100% in rain-fed crops. Data from Pretty and Hine (2001) have been challenged by some authors (e.g., McDonald *et al*., 2005; Cassman, 2007; Hudson Institute, 2007; Hendrix, 2007), who dispute the correctness of both the accounting (they hold that, in some of the cases reported, pesticides may have been used) and comparative methods employed. Cassman (2007) criticizes both the findings and the approach to the problem of food security adopted by the supporters of organic farming, and argues that what is needed to produce 60% more food by 2050 to meet demand from growth in both population and income is ecological intensification of crop production systems rather than relying on the organic farming approach.

F. "Food Miles" Analysis

Most energy in the food system is post-production. Food processing, distribution, wholesale and retail can amount to two thirds of total energy expenditure (Pimentel and Pimentel, 2008; Smil, 2008). It has been estimated that in the United States, on-farm production amounts to approximately 20% of the total food system energy, with about 40% of this amount going into making chemical fertilizers and pesticides (Keoleian and Keoleian, 2000).

National and international trade results in increasing "food miles" (the distance that food travels from the field to the grocery store), which may lead to increasing the overall energy consumption and CO_2 emissions associated with a given product (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, 2008). 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. This, however, may limit export of organic products from developing countries to western markets, reducing the income for poor farmers and the adoption of sustainable farming practices.

Some authors challenge such a claim as too simplistic a view, and make the point that agricultural products imported from far away may cause lower environmental impact than locally produced products, for example when the latter have to be kept stored in fridges for several months (e.g., fruits) (Wells, 2001; Saunders *et al*., 2006; Williams, 2007; El-Hage Scialabba and Müller-Lindenlauf, 2010). Saunders *et al*. (2006), for instance, report that in the case of dairy and sheep meat production, New Zealand is by far more energy efficient than the UK even including transport costs, twice as efficient in the case of dairy, and four times as efficient in case of sheep meat. Wells (2001) found that New Zealand dairy production was on average less energy intensive than in North America or Europe even though on-farm primary energy input had doubled in 20 years and energy ratio (outputs vs. inputs) had increased by 10%. Williams (2007) reports that Dutch CO_2 emissions for rose cultivation were about 6 times larger than producing them in Kenya and delivering the product to Europe.

VII. CONCLUSIONS

In the last century, intensive farming has successfully achieved high crop yields. On the other hand this came with a cost on the environmental side because of the high intensity of energy use (agrochemical, machinery, water pumping etc) and GHGs emissions, water consumption and the large use of agrochemicals, which, other than being costly in energy terms, have also detrimental effects on the health of organisms, humans included.

When comparing the performances of organic and conventional agricultural practices it has been shown that organic generally performs better or much better than conventional for a wide

range of key indicators (Table 1). Such improved performances have been summarised in previous reviews such as Stölze *et al*. (2000), Stockdale *et al*. (2001); FAO (2002), Lotter *et al*. (2003), Shepherd *et al*. (2003), Kasperczyk and Knickel (2006), Niggli *et al*. (2007), Gomiero *et al*. (2008), as well as proven in long term monitoring trials (e.g., Reganold *et al*., 1987; Matson *et al*., 1997; Paoletti *et al*., 1998, Drinkwater *et al*., 1998; Mäder *et al.,* 2002a, 2002b; Pacini *et al.,* 2003; Pimentel *et al*., 2005; Badgley *et al*., 2007). However, it has to be pointed out that in some cases performance can vary according to specific crop species and crop patterns and in relation to the environmental context where agricultural activity is performed.

In the following section we provide some more detailed comments on the performances of organic agriculture on some key environmental issues. We will deal in particular with soil, biodiversity, energy and GHG emission.

Table 6 is an attempt to further develop the qualitative review efforts made by Stölze *et al*. (2000) and Lotter, (2003). Assessments are only indicative and no claim is made to provide weighted qualitative values of farming performance.

As pointed out by Pacini *et al.* (2003), the fact that in most cases organic farming systems perform better environmentally than conventional or integrated farming system, does not directly imply that they are sustainable when compared to the intrinsic carrying capacity and resilience of a given ecosystem. Comparison between organic and conventional (or other) farming systems is much needed, but to assess sustainability in the long term, proper comparisons have to be made taking into account the local (and global) carrying capacity of the agroecosystem.

To date, many studies prove organic farming to perform better in improving soil quality with respect to both biophysical and ecological properties. Organic farming prevents soil erosion, increases SOM (promoting soil biodiversity and soil health) and can reduce N leaching. Increases in SOM following the transition to organic management occur slowly. This has to be of concern when assessing the performances of farming systems under different management practices. Soil under organic management greatly increases their water holding capability and under drought conditions crops in organically managed systems produce higher yields than comparable crops managed conventionally. Adaptive measures to cope with climate change should treasure knowledge gained from organic farming. Local characteristics deserve attention, as agricultural practices should not be adopted blindly, but with much concern for specific local features. What may fit a given area may not be practicable with the same results in another (e.g., plain vs. sloping land).

Agriculture intensification results also in a dramatic simplification of landscape composition and in a sharp decline of biodiversity. This affects the functioning of natural pest control, as natural habitats provide shelter for a broad spectrum of natural species that operate as pest-control in agriculture crops. Organic farming tends to rely on a higher number of crops, compared to conventional, because of the very nature of the management system, involving rotation, cover crops, intercropping and set

TABLE 6

Overall qualitative assessment of organic farming systems relative to conventional farming*. (Organic farming performs: ++ much better, + better, 0 the same, − worse, – much worse).

Indicator − Performance	Qualitative Assessment				
	++	+	0	−	−−
Agronomic					
Productivity as yield per ha		+	0	−	−−
Productivity as yield per hr				−	−−
Biodiversity					
Crop diversity	++	+	0		
Floral diversity	++	+			
Aboveground faunal diversity (invertebrate and vertebrate)	++	+			
Habitat diversity	++	+	0		
Effect on pest control and pollinators	++	+			
Soil biophysical characteristics					
Organic matter	++	+	0		
Structure	++	+	0		
Soil biology	++	+	0	−	
Microbial biomass	++	+			
Microbial activity	++	+			
Mycorrhizae	++				
Biodiversity	++	+			
Effect on pest control	++	+	0		
Ground and surface water					
Nitrate leaching	++	+	0	−	
Pesticides	++				
Greenhouse emissions (including CO_2, CH_4, N_2O, NH_3)					
GHGs per ha	++	+			
GHGs per ton biomass		+	0	−	
Farm input and output					
Nutrient use		+			
Water use		+	0		
Energy use per ha	++	+			
Energy use per ton biomass		+	0	−	
Animal welfare and health					
Husbandry		+			
Health	++	+			
Quality of product food					
Pesticides residues	++	+			
Nitrate		+	0	−	
Mycotoxins		+	0	−	
Heavy metals		+	0	−	
Antibiotics	++				

(*): the list of indicators has been expanded from Stölze *et al*. (2000) and Lotter (2003), and quality assessment modified according to the data found by the present review.

aside. A more complex crop pattern offers more chances for "wild biodiversity" to thrive.

According to the studies reviewed, organic farming provides greater potential for biodiversity than its conventional counterpart, as a result of greater habitat variability and more wildlife-friendly management practices, and, to a lesser extent, due to the exclusion of pesticides. This greater potential is more readily observed primarily for wild plants, but also for their hosts. Indeed, an increasing body of evidence indicates that landscape heterogeneity is a key factor in promoting biodiversity in the agricultural landscape.

The effect of organic agriculture on promoting biodiversity may also vary according to the specific taxa and the surrounding conditions where a farm operates. Research indicates the need for long term, system-level studies of the biodiversity response to organic farming. It is noted that such benefits may be achieved also by conventional agriculture when carefully managed.

Promoting heterogeneity widely across agricultural systems should be a universal management objective. Large areas converted to organic management may generate positive feedbacks on biodiversity because of scale effect (the larger the areas the greater the benefits), suggesting that measures to preserve and enhance biodiversity in agroecosystems should be both landscape- and farm-specific.

Energy efficiency and GHG emission reduction are certainly important indicators of farming system performances. Organic farming has been shown to providing a better of energy input/output ratio. The main reasons for higher efficiency are lack of input of synthetic agrochemical (e.g., fertilizers, pesticides) and lower use of highly energy-consumptive foodstuffs (concentrates). However, due to the general lower yield of crops under organic farming, when calculating energy input in terms of unit of physical output, the advantage to organic systems was generally not as significant. Organic agriculture may represent a means for reducing GHG emission, both because of its lower energy consumption and of its soil management practices that help to reduce GHG emission and absorb carbon in soil. Conversion to organic agriculture, however, only represents a temporary solution to the problem of carbon abatement because the possibility to stock carbon in the soil has limits. Long-term solutions concerning CO_2 and GHG emission abatement should rely on a more general change of our development path, for instance in containing energy consumption in general. Other beneficial "by-products" provided by organic farming both for the environment (e.g., reducing pollution, fostering biodiversity) and for human health (e.g., exposure to harmful chemicals), also should be properly accounted for.

Carrying out extensive long-term trials for diverse crops in diverse areas would be of fundamental importance in order 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.

According to Niggli *et al*. (2008), there are three strategic research priorities for agricultural and food research:

- Viable concepts for the empowerment of rural economies in a regional and global context
- Securing food and ecosystems by means of eco-functional agricultural intensification
- High quality foods—a basis for healthy diets and a key for improving our quality of life and health.

Researching organic food and farming systems can contribute greatly towards the overall sustainability of agriculture and food production by providing a holistic analysis of system factor interactions and trade-offs in order to meet new challenges.

We would like to conclude by reminding each of us that we all depend inescapably on agriculture for our life. We feel that maybe there has been too much focus on agriculture as a mere economic activity, forgetting that, differently from all other economic activities, this is the only one that we cannot afford to dismiss or allow ourselves to lose.

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