ISSUES PAPER: ORGANIC AGRICULTURE AND ENVIRONMENTAL STABILITY OF THE FOOD SUPPLY

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I. INTRODUCTION

1. Stability of the food supply is broadly related to the environmental conditions that allow for sustainable food production and encourage productivity as well as to the economic conditions that allow for sustainable supplies at reasonable prices. This paper focuses on the interactions and interdependencies between farming practices and environmental conditions. By producing food, farmers can improve or degrade the environment they depend on. Both favorable and stable environmental conditions and agricultural systems resistant or resilient to environmental changes are crucial for the stability of food production.

2. Stability of food supply is also associated with other dimensions of food security, such as access to food and food utilization, as well as economic conditions of food stability. This paper reviews the literature on food stability and the environmental factors that contribute to it with respect to organic agriculture. Organic agriculture here includes both those production systems organized around distinct organic and biodynamic certification schemes that are "certified organic agriculture" and those that, by virtue of their production systems, follow organic principles but are "non-certified organic".

3. Organic agriculture is a system that uses less intensive practices. It is, therefore, expected to deliver far more ecological goods and services than conventional agriculture, even in its modified forms such as integrated farming or minimum tillage. Furthermore, organic agriculture efficiently reduces environmental risks by not using some potentially damaging technologies of intensive agriculture such as pesticides, herbicides, synthetic nitrogen fertilizers, GMO crops or veterinary antibiotics and anthelminthics. The ecological goods and services of organic agriculture are reviewed in El-Hage Scialabba and Hattam (2002), Shepherd, et al. (2003) and Stolze, et al. (2000).

4. In broad terms, organic agriculture can be described as increased diversification on both farm and regional scale. It is a system that leads farmers and rural communities to economic independence from expensive agricultural inputs through their use of participatory seed-breeding systems; natural bio-control agents; soil fertility management through recycling, nitrogen fixation and green manure; and habitat management as a prevention strategy against pests, diseases and weeds.

5. Currently, 0.61 percent of the world's reported agriculture land is certified organic agriculture. There are no recent data on the extent of non-certified organic agriculture. However, it is widely known that a large part of global food production systems is non-certified organic agriculture, often at subsistence level.

II. ENVIRONMENTAL INFLUENCES ON FOOD SUPPLY STABILITY

6. The key environmental influences on the performance of agricultural systems are soil and water resources, biodiversity and climate. Agriculture is both perpetrator of changes – in most cases environmental deterioration – and victim. Among all concepts of sustainable land use practices, organic agriculture is the most consequential approach, in terms of ecological sustainability.

7. With respect to the quality of sustainability of organic agriculture, two observations can be made.

- Sustainability from organic systems is based on standards that advocate restrictions or bans on the input side. However, metrically measurable standards on the impact side (e.g. minimum percentage of high quality ecological areas such as hedge rows, field margins and species rich wildflower strips, or minimum of crops in a rotation) would improve the sustainability of organic agriculture even more. As they are very region specific, such standards focusing on positive environmental impacts can only be introduced in regional or national standards as has been done in Switzerland.
- Organic agriculture is a multi-targeted approach to sustainability. Unlike conventional farming, it does not focus on individual high impact measures. For example, the “no till” technique used in conventional farming efficiently prevents soils erosion but needs more herbicides and soluble nitrogen fertilizers and often promotes soil borne diseases leading to need for additional fungicidal treatments.

A. ORGANIC AGRICULTURE AND STABILITY AND FERTILITY OF SOILS

8. In order to meet the world’s current and future food demand, food supply stability will be needed to maintain agricultural productivity at least at the current level without negative effects on soils or the environment. In addition, the expanding human population will require more secure and improved yields and additional acreage. Yield increases resulting from the so-called “Green Revolution” have slowed and are currently linked to soil degradation (Kaiser, 2004), which is considered a threat to food supply stability. Pimentel, et al. (1995) calculated a loss of nearly a third of the world’s arable land to erosion within the last 40 years with an on-going loss of more than 10 million ha per year. Bellamy, et al. (2005) found massive losses of carbon in soils across England between 1978 and 2003. Their estimates ranged from 0.5 to 2 g soil carbon per kg soil per year with all but 8 percent of the investigated cropland affected by erosion – a factor the authors identified as the main reason for losses in soil carbon and therefore in soil fertility. This highlights that current land use practices are not sustainable.

9. Reganold, et al. (1987), in comparing soils from organic and conventional farms in Washington, USA, found organic fields had topsoils 16 cm deeper and a higher organic matter content which resulted in soils less prone to erosion. A long-term Swiss field experiment on loess soil that began in 1978 (Mäder, et al., 2002) found the aggregate and percolation stability of both bio-dynamic and organic plots were significantly higher (10 to 60 percent) 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., 2002). 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), repeated measurements of aggregate stability in plots with livestock-based integrated production (mineral and organic fertilizers, herbicides and pesticides) found 29.4 percent higher values while in organic and bio-dynamic plots (organic fertilizers only), it was 70 percent higher (Siegrist, et al., 1998). The Swiss long-term study underlines the importance of using manure, by means of organic agriculture, as a good practice for soil quality preservation (Fließbach, et al. 2007).

10. Similar results were obtained under on-farm conditions in the Netherlands in a polder soil, which is considered prime agricultural land for Dutch arable crop production (Pulleman, et al., 2003).

The percentage of water stable macro-aggregates on organically farmed sites was 72 percent higher compared to conventional. The higher physical stability was linked to significantly increased soil organic matter content and to a larger volume percentage of worm-worked soil (organic 28 percent and conventional 8 percent). The investigation was done on farms that had been under organic and conventional management for 70 years. A study of cotton production under organic conditions in India found yield levels similar to a modern cultivation technique, but soil quality, as indicated by soil organic matter, water stable aggregates and mean weight diameter, showed advantages for the organic system (Blaise, 2006).

11. The Rodale farming systems trial, that began in 1981 in Pennsylvania, USA, compared manure and legume-based organic agriculture systems to a conventional system based on mineral fertilizers (Hepperly, et al., 2006). It found the organic and conventional systems had similar soybean and maize yields whereas the organic system showed an impressive increase in soil carbon of 574 kg per ha in the legume-based and 981 kg ha-1 in the manure-based system.

12. Soil macrofauna, such as worms, ants and termites that are actively involved in the build-up of soil structure, have positive effects on water infiltration, drainage, water-holding capacity and soil aeration (Giller, et al., 2003). These and other beneficial soil biota help process nutrients from residues for plant uptake while also creating stable organic matter. Several field studies found earthworms and other soil fauna such as carabides, spiders and staphylinides were more abundant in organic fields than conventional ones (Pfiffner and Niggli, 1996; Pfiffner, 1997; Pfiffner and Mäder, 1997; Birkhofer, et al., submitted). A more diverse food and micro-landscape (weeds and soil structure) and the absence of potentially toxic pesticides are the main factors favouring macrofauna in organic systems.

13. The predominant practice in organic agriculture is the on-farm flux of manure from livestock production to cropland. However, even stockless organic farms use leguminous plants for nitrogen fixation and green manure for building up soil fertility. Catch crops for soil nutrients, especially nitrogen, integrated in different positions of the rotations, help manage nitrogen intelligently, especially in temperate climatic zones where nitrogen losses are likely to occur (Thorup-Kristensen, et al., 2003).

14. Soil organic matter, a key to soil fertility throughout agriculture, is understood to contribute significantly to soil quality and health (Quiroga, et al., 2006). Soil organic matter drives and enhances numerous chemical and biological processes and physical soil properties (Fan, et al., 2005). Higher levels of soil organic matter have been observed regularly in organic agriculture soils compared to conventional (Pimentel, et al., 2006; Fließbach, et al., 2007; Marinari, et al., 2007). In one study, soil organic matter was higher in organically managed soil than in conventional soil despite relatively similar totals of organic carbon (Marinari, et al., 2007).

15. Marriott and Wander (2006) analyzed soil samples from nine farming system trials that were started in the USA between 1981 and 2000. The soil organic carbon concentrations were 14 percent higher in organic systems than in conventional ones. The labile fraction of the soil organic matter – a source of mineralizable C and N with important implications for plant nutrition – showed 30 to 40 percent higher values in organic soils. Enhancing soil organic matter improves soil fertility and, in the long-term, has the potential to increase crop yields (Fan, et al., 2005).

16. Parallel to the changes of organic matter in soils of organically managed systems, soil microbial biomass and the physiological functions of soils are enhanced by organic agriculture. Important soil enzyme activities such as dehydrogenase, protease and phosphatase were higher in organic field plots leading, for example, to a faster phosphorus flux through the microbial biomass contributing to the plants’ phosphorus supply (Mäder, et al., 2002). Field trial soils that received only mineral fertilizers in a conventional system showed a 52 percent higher basal respiration per unit of microbial biomass than organic soils, suggesting that micro-organisms in organic soils use organic substances more efficiently for growth than for maintenance (Fließbach, et al., 1997, 2007).

17. In summary, organic practices contribute considerably to increasing soil stability and resilience, the latter reflects the time needed to recover from disturbances, an important factor in food supply stability. The productivity of organic compared to conventional farming depends strongly on soil and climate conditions as well as on choice of crops being compared. Under less favorable soil conditions, organically managed crop yields equal those from conventional agriculture, as was shown for maize and soybeans in the USA by Pimentel, et al. (2005). In organic cotton production in India, Eyhorn, et al. (2007) also reported no yield differences from organic compared to conventional farms. In a fertile soil in a temperate climate in Switzerland, total yields of the organic 7-year crop rotation were 20 percent lower than the conventional one (Mäder, et al., 2002), but had a significantly better output/input ratio for nutrients, energy and pesticides in the case of organic practice. When soil and climate conditions are extremely favorable, yield losses of organic crop rotations may exceed 30 percent of conventional ones. This may also apply to crops with peculiar plant protection demands and short vegetation periods.

18. In comparison to other modern approaches to improving crop yields and soil quality in order to prevent soil erosion such as minimum or no tillage systems (Holland, 2004), organic agriculture advocates a site-adapted multifactorial strategy without the use of synthetic fertilizers or pesticides. Instead, organic agriculture makes use of available production factors that mainly derive from the farm-ecosystem itself. The combination of techniques – organic agriculture and minimum or reduced tillage – is a challenging subject for future research in this field. Long-term field experiments addressing this area are underway (Berner, et al. submitted) and need to be performed under different site and climate conditions.

B. ORGANIC AGRICULTURE AND WATER EFFICIENCY

19. Organic agriculture practices have the potential to use less water and to use water more efficiently due to vegetation and soil management. Soil and water use are inextricably linked in agricultural production. During the twentieth century, humans increased the diversion of river water by six-fold (Pretty, et al., 2006). By 2025, as many as 60 percent of all humans may face a scarcity of water (Qadir et al., 2007). Currently, 70 percent of human water use is directed towards agriculture. As water becomes increasingly scarce in certain regions of the world, it will be important to increase water efficiency in irrigation and rain-fed agriculture. Water use efficiency is a calculation determined by the amount of crop yielded from an amount of water (Hatfield, et al., 2001). Pretty, et al. (2006) outlined several ways to improve water use efficiency in organic agriculture, including reducing evaporation through minimum tillage, using more water-efficient varieties and inducing microclimatic changes to reduce crop water requirements.

20. The soil fertility-building techniques of organic agriculture that lead to higher organic matter contents, better aggregate stability and, biologically, more active soils in turn, increase water retention in soils and improve the water use efficiency (Mäder, et al., 2002; Pimentel, et al., 2005). Pimentel et al. (2005) reported 28 to 34 percent higher corn yields in the Rodale experiment in Pennsylvania in the organically managed plots in years with drought. During the 2003 summer drought in Europe, similar observations were made with wheat although not scientifically analyzed.

21. Additionally, the presence of soil macrofauna, which are promoted through organic agriculture, can enhance soil water availability (Ouedraogo, et al., 2006). A few studies have shown that organically managed agriculture fields have less water run-off. In the Rodale experiment, water volumes percolating through the organic systems were 15 to 20 percent higher than through the conventional one, indicating an increase in groundwater recharge and reduced run-off. Similar data was obtained in the DOK trial in Switzerland where percolation stability of organic and bio-dynamic soils was 40 percent higher than of conventional ones (Mäder, et al., 2002).

22. In general, different agricultural techniques used in organic agriculture affect water use efficiency. Tillage, soil residue management, soil temperature, soil nutrients and structure effect water use efficiency (Hatfield, et al., 2001; Hati, et al., 2006). Different degrees of tillage can either increase or decrease water infiltration while also increasing the rate of soil drying (Hatfield et al., 2001). Maintenance of either a cover crop or harvest residue can maintain soil moisture and water use efficiency by increasing water infiltration and cooling the soil surface to a greater degree than tillage that incorporates stubble in the soil (Hatfield, et al., 2001). Thus, no-till planting that maintains a cover crop while minimally disturbing the soil surface can increase water use efficiency (Hatfield et al., 2001). Unfortunately, field experiments comparing the effect of well managed organic systems on water use efficiency with that of good conventional no-till systems do not exist. It can be assumed that organic systems with elements of minimum tillage would be very powerful in terms of water and soil erosion management. In India, although not scientifically analysed observation from biodynamic systems suggest decreased irrigation need by 30 to 50%: this is due to characteristics such as significantly superior soil structure, friability, aeration and drainage, lower bulk density, higher organic matter content, soil respiration (related to soil microbial activity), more earthworms and deeper topsoil layer (Proctor and Cole, 2002).

23. Organic management practices also decrease pollution in water effluent. In addition to maximizing water use efficiency in agriculture, it will also be important to decrease the amount of water polluted by agricultural practices for the sake of downstream users and aquatic biodiversity. The prohibition of pesticides and inorganic fertilizers in organic food production is an important step towards removing these pollutants from the aquatic environment. Nitrates are also an agricultural pollutant produced by nitrogen fertilization, both organic and inorganic. Organic agriculture, however, has demonstrated reduced nitrate leaching rates, ranking from 40 percent to 64 percent in different soil types in Europe (see the meta study of Stolze, et al., 2000). These effects are less the result of the organic fertilization technique, as the use of manure and slurry is also prone to nitrate leaching. Reduction in nitrate leaching can only be obtained by carefully designed crop rotations including catch and cover crops (Thorup-Kristensens, et al., 2003, 2007). As the opportunity costs of nitrogen on organic farms are 7 to 16 times higher than with mineral fertilizers, these rotational techniques are widely used on organic farms.

24. In summary, food security, in light of regional water scarcity, will ultimately require “more crop per drop”. Organic agriculture can increase water use efficiency through improved soil management and by reducing pollutants.

C. ORGANIC AGRICULTURE AND SYSTEM STABILITY THROUGH BIODIVERSITY

25. Biodiversity is an important driving factor for system stability, and organic agriculture, in particular organic pest and disease management, is based on a most stabilized system. Organic agriculture has been shown to promote more species and have more abundance of organism groups than conventional farming (Bengtsson, et al., 2005; Hole, et al., 2005). Stability of agroecosystems can be optimized through the implementation of appropriate soil fertility management and habitat management (Altieri et al., 2005). Moreover, green manures, application of manure and broad crop rotations within organic farmland lead to greater species diversity and density for insects, plants, soil macrofauna and soil microfauna, although some taxa will not be significantly affected (e.g. Fuller, et al., 2005; Gabriel, et al., 2007). An over-riding determinant of biodiversity may be habitat diversity, rather than management practices (Weibull, et al., 2003).

26. Genetic diversity of crops within conventional farms is very low – usually one variety per planting. Organically grown crops can be just as genetically limited but, organic farms have a greater diversity due to mandatory crop rotation. However, one pillar of organic plant protection and animal health is the use of a more diverse range of disease, pest and parasite tolerant or resistant varieties and breeding lines. In most organic crops and in animal husbandry, the use of this genetic diversity is part of the economic strategy to control pests, diseases and parasites.

27. The potential of genetic diversity on crop level for stabilization of low-input farming systems and for adaptation to environmental changes is theoretically understood in organic quarters but unfortunately not yet practically used. Cultivar or race choice is still strongly based on immediate market needs; traditional regional or local varieties are niches even in organic agriculture, and in situ concepts of conservation and breeding on farms or in rural communities are still underdeveloped. Kotschi (2006) considered agrobiodiversity a fundamental resource for adaptation and therefore crucial for the stability of food supply. As resistance and robustness to environmental stress are multi-genetic characteristics, the in situ conservation and on-farm breeding are likely to be more successful than genetic engineering. There are many very small initiatives by plant and animal breeders in the context of organic farms scattered around the world. These initiatives urgently need political, scientific and economic support.

28. To show the importance of biodiversity for stability in organic agriculture systems, the strategy of plant protection is exemplary. Organic pest and disease management is based on indirect and direct control measures. Wyss, et al. (2005) proposed a conceptual model for arthropod pest management for organic crop production. In this model, indirect, preventative measures are of highest priority. They are to be considered early in the adoption process, followed by more direct and curative measures only when needed. Zehnder, et al. (2007) reviewed the preventative and direct measures of this model for organic crops. They concluded that the establishment of an organic production system needs to consider aspects such as landscape complexity to ensure that sufficient semi-natural landscape elements are present to serve as natural enemies that could be attracted by conservation biocontrol methods (e.g. planting hedges, sowing weed strips, installing beetle banks). Soil quality management (e.g. amendment with compost), tillage practices (e.g. conservation tillage), host plant

resistance, crop rotation and intercropping are important additional measures to lower risks of pest and disease outbreaks. Based on just these preventative measures, direct plant protection measures (inundation and inoculation biocontrol, pesticides of vegetal and mineral origin) can be used efficiently by farmers and can therefore be limited. In other words, biodiversity in organic agriculture has a clear function a functional biodiversity that stabilizes the agricultural systems.

29. In conclusion, organic farmers strive for the protection of a diverse landscape with habitats managed to host and attract beneficial organisms. They use a broad crop rotation with a large set of tolerant varieties on a healthy, diverse soil to get the most stability possible. This stability is based on biodiversity (below and above ground) and is the best guarantee for stable production in organic, low-input agriculture. As a result, this biodiversity-driven stability leads to a more stable food supply.

III. POTENTIALS AND DEFICITS OF ORGANIC AGRICULTURE UNDER CLIMATE CHANGE SCENARIOS

30. Climate change will dramatically alter international food supplies. Five factors expected with climate change – rise in temperature, changes in precipitation patterns, rise of sea levels, higher incidence of extreme weather events (droughts, storms, floods) and an increase of greenhouse gases (especially carbon dioxide) in the atmosphere – will all influence food production.

31. Models predict that average global temperatures will increase between 1.8º and 4.0ºC at the end of the twenty-first century (IPCC Report 2007) and will be accompanied by random alterations (both temporal and geographic) in precipitation patterns (Mendelsohn and Williams, 2006). These models, which contain a degree of uncertainty, project an increase in agricultural productivity for mid- and high-latitude areas, but a large decrease in low-latitude agricultural productivity (Mendelsohn and Williams, 2006). These estimates of net positive and negative effects of climate change on food security take into account the positive effects of increased CO2 on plant growth, reductions in plant water use, and the possibility that new areas for agricultural production will emerge. Negative effects include increased flooding of low-lying areas; increased drought, particularly in tropical countries; and the likelihood of reduced yields in areas affected by decreased precipitation and other changes in climatic conditions.

32. Land suitable for agricultural land may increase by as much as 40 percent in some developed countries while less developed tropical countries may witness a reduction in agricultural productivity by 5 to 10 percent (Fischer, et al., 2005). As for grazing lands, forage yields are predicted to decrease between 16 and 25 percent (Steinfeld, et al., 2006). A forthcoming IPPC report on specific global effects of climate change predicts that negative effects will occur disproportionately in equatorial countries compared to temperate ones. The 40 poorest countries located predominantly in tropical Africa and Latin America might lose 10 to 20 percent of their crop production capacity by 2080, mainly due to drought (Kotschi, 2006). It is therefore important that resilience of the food supply be maintained and promoted in those places where agriculture is most vulnerable.

33. Aside from the ability of certain regions to maintain agricultural productivity, irrigation requirements will change with the climate. Fischer, et al. (2006) predict that global water withdrawals for irrigation will increase by 20 percent as a result of climate change, in addition to a 25 percent increase that will result from a 45 percent expansion of irrigated cropland in parallel to a 20 percent

increase in irrigation efficiency (this means decreased water needs). Around two-thirds of the climate-change-induced increases in water requirements will occur within developing countries.

34. Combating such changes requires mitigation and adaptation strategies. Above all, all possible efforts are needed to reduce greenhouse gas emissions and to slow climate change. In addition, action is needed to enhance the capacity of agricultural production systems to adapt to irreversible changes. Organic agriculture is a whole food chain approach with unique features that differ from mainstream food and farming production. One can assume that organic agriculture not only enables agro-ecosystems to better adapt to the effects of climate change but also has high potential to reduce the emissions of agricultural greenhouse gases. It is therefore critical to analyze the major characteristics of organic food and farming systems in the light of their potential for mitigation and adaptation. Complementary to strong points, deficits of organic food and farming systems will be discussed and recommendations will be made for research and development and for standard-setting actions.

A. POTENTIAL OF ORGANIC AGRICULTURE FOR MITIGATION

35. Agriculture accounts for 15 percent of the total emission of greenhouse gases (GHG). The whole food chain, including transportation, storage, processing, consumption and preparation, adds up to 20 percent of the total GHG (figure calculated for Germany, von Koerber and Kretschmer, 2006). Of this, agriculture is responsible for emitting one quarter of the carbon dioxide, two-thirds of the methane and 65 to 80 percent of the nitrous oxide (IPPC, 2001).

36. Afforestation is recognized as a major land use change mitigating climate change. However, crop land management is overestimated for its potential for carbon sequestration especially in Europe (Smith, et al., 2005). Smith, et al., concluded that “the only trend in agriculture that may be enhancing carbon stocks on croplands at present is organic agriculture, and the magnitude of this effect is highly uncertain.”

37. Organic agriculture offers a wide range of very significant side effects to be seriously considered in the light of reducing GHG emissions in agriculture. Major factors are i) the reduced consumption of fossil fuels for energy, ii) the reduced emissions of carbon dioxide, methane and nitrious dioxide, iii) the considerably reduced vulnerability of soils to erosion accompanied by organic matter respiration, and iv) the increase of carbon stocks which is part of organic management practice and is especially high in already degraded soils.

38. Energy consumption per land unit has been shown to be 10 to 70 percent lower in all organic crops in five European countries (Geier, et al., 2001; Kus and Stalenga, 2000; Wetterich and Haas, 1999; Cederberg and Mattsson, 1998; Alföldi, et al., 1995; Reitmayr, 1995; Barbera and La Mantia, 1995; Haas and Köpke, 1994). Due to the lower yields of organic production systems, the energy consumption per product unit is low for wheat, milk, citrus and olive (15 to 54 percent lower in organic systems than in conventional ones) but for potatoes and apples, organic energy use equal or higher than for conventional crops. A study from Iran (Zarea, et al., 2000) found organic to be 81 percent more energy efficient than high-input conventional production. For the Rodale long-term experiment in the USA, the energy inputs per ha for the organic systems were 28 to 32 percent less than those of the conventional ones. As the yields of both systems were equal, the relative advantage of organic remained the same per unit produce.

39. Organic soil fertility management offers a unique possibility to replace fossil-fuel-based nitrogen fertilizers. In the UK, a 100 ha stockless arable farm consumes 17 000 litres of fossil fuel annually through fertilizer inputs. The nitrogen self-reliance of organic systems is a major advantage in times of fossil energy shortage (Cormack, 2000).

40. Comparative data on the emission of greenhouse gases for organic and conventional systems are rare. Available data show that parallel to the lower energy consumption of organic production, the CO2 emissions are also lower, between 48 and 60 percent (Burdick, 1994; Haas and Köpke, 1994). Nemecek, et al. (2005) found greenhouse warming potential in organic systems 29 to 32 percent lower on a per ha basis than in a mineral fertilizer system and 35 to 37 percent lower than in the conventional manure-based system. This results from the omission of synthetic fertilizers and pesticides as well as less use of high energy feedstuff.

41. In most cases, organic systems are also advantageous per unit yield, especially for dairy and meat production (Bos, et al., 2007) and for most arable crops (Nemecek, et al., 2005). For technically difficult crops such as potatoes, grape and fruits (with insufficient pest and disease control), as well as for very intensive crops (that require soil tillage and organic fertilizer input), organic vegetable and arable crop systems have equal or higher CO2 emissions than conventional ones (Haas and Köpke, 1994; Bos, et al., 2007).

42. As far as N20 and methane emissions are concerned, no data on organic production is available at the moment. Models used for comparing farms or production units do not differentiate between organic and conventional. Nonetheless, some inherent characteristics of organic systems are likely to lower N20 and methane emissions. N20 emission is directly linked to the concentrations of easily available mineral nitrogen in soils. Denitrification is additionally enhanced in compacted soils. Organic soils have significantly less mobile nitrogen concentrations and – thanks to the excellent soils structure – are more aerated. Both of these factors reduce N20 emission considerably. Permanent plant covers which are part of many organic cropping systems further reduce N20 emission. Methane emissions of organic rice and ruminant production equal those of conventional ones. In cattle breeding, longevity is a characteristic of organic systems (Verhoog et al., 2004). The ratio between the unproductive phase of young cattle and the productive phase of dairy cows is favourable in organic systems as far as methane emissions are concerned.

43. Soil erosion on agricultural land is accompanied by massive losses of carbon into the atmosphere. These losses occur in arable land (wind and water erosion) as well as on pastures (overgrazing through cattle, sheep and goats). Organically managed soils are significantly less prone to erosion (see the section “Organic agriculture and the stability and fertility of soils” for data) and organic standards do not allow overgrazing as livestock charge is strictly limited per land area in respect to site specific productivity. Although many improvements in conventional arable systems have been discussed for decades, carbon loss is not slowing and, in fact, continues at high rates (Bellamy et al., 2005; Pimentel, et al., 1995).

44. The carbon sequestration efficiency (tonnes CO2-C per ha) of organic systems in temperate climates is almost double compared to conventional ones, when the total of above and below ground biomass of cash and catch crops and weeds is calculated (Köpke and Haas, 1994). All farm comparisons and long-term field trials show significantly higher soil organic matter content when organically managed (see chapter “Organic agriculture and the stability and fertility of soils” for data). In the Swiss long-term DOK experiment (Mäder, et al., 2002), in 28 years, the organic systems

accumulated 12 percent and the bio-dynamic system accumulated 15 percent more carbon in the soil. The carbon sequestration rate was 157 to 191 kg carbon per ha per year. In the Rodale experiment in the USA, Pimentel, et al. (2005) reported an annual soil carbon increase of 981 kg per ha in the manure-based organic system and an increase of 574 kg per ha in the legume-based organic system. Carbon sequestration was on a perfectly comparable level in both the Swiss and USA long-term field experiments.

45. Foereid & Høgh-Jensen (2004) estimated that a Northern Europe conversion from conventional arable crops to organic crops would result in an increase in organic soil matter during the first 50 years of about 10 to 40 g C per m2 per year. The steady state (a stable level of soil organic matter) would be reached after 100 years. They found the main factors for the increase in organic matter were use of grass clovers for feedstuff and of cover crops in organic rotations.

B. POTENTIAL OF ORGANIC AGRICULTURE FOR BETTER ADAPTATION TO CLIMATE CHANGE

46. The Intergovernmental Panel on Climate Change (IPCC, 2001) defines adaptation to climate change as “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.” This definition puts emphasis on the importance of farmer knowledge for adaptation to climate change, especially as its impact is very site specific (local) and all scenarios are very complex and unpredictable in many aspects. Therefore, Borron (2006) looked specifically into farm “community knowledge as a form of adaptive management.”

47. Traditional skills and knowledge have been neglected in intensive agriculture although now they are being partly recaptured by integrated pest management. However, organic agriculture has always been based on practical farming skills, observation, personal experience and intuition. Knowledge replaces or reduces reliance on inputs. This knowledge is important for manipulating complex agro-ecosystems, for the breeding of locally adjusted seeds and livestock, and for the production of on-farm fertilizers (compost, manure, green manure) and inexpensive nature-derived pesticides. Tengo and Belfrages (2004) described such knowledge as a “reservoir of adaptations” (see OFS/2007/2 for more details on knowledge in organic systems).

48. Agricultural production systems that emphasize resilience, resistance and site-specific adaptation to changing soil and water conditions, such as organic systems, are potentially well-positioned to maintain production in the face of climate change.

49. Ewel (1986) describes soil organic matter as “the warehouse of most of the nitrogen, phosphorus, and sulphur potentially available to plants, is the main energy source for microorganisms and is a key determinant of soil structure.” This underlines the importance of the findings concerning organic agriculture and soil fertility described in the previous section “Organic agriculture and stability and fertility of soils”.

50. Farming practices such as organic agriculture that preserve soil fertility and maintain or even build up organic matter in soils are definitely well positioned to maintain productivity in case of drought, irregular rainfall events with floods, and rising temperature. Soils under organic management retain significantly more rainwater thanks to the “sponge properties” of organic matter. This was

described for heavy loess soils in a temperate climate in Switzerland (Mäder et al., 2002) where water infiltration capacity was 20 to 40 percent higher in organically managed soils than in conventional ones. 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 litres per ha. This water reservoir was likely the reason for higher yields of corn and soybean in dry years. Lotter, et al. (2003) found that water capture in organic plots was approximately 100 percent higher than in conventional plots during torrential rains. This reduced the risk of floods significantly, an effect that could be very important if organic agriculture were practiced on much bigger areas.

51. An additional strength of organic agriculture systems is their diversity at all levels including crop, fields, whole rotations, polycultures, farm activities (greater mix of different branches), and landscape on the farms. The high diversity of organic farms (see section “Organic agriculture and system stability through biodiversity” for data) provides many ecological services that enhance farm resilience tremendously. Positive effects on pest prevention have been proven by Zehnder et al. (2007), Wyss, et al. (2005) and Pfiffner, et al. (2003). Similar effects of diversified agro-ecosystems on diseases and better utilization of soil nutrients and water (Altieri and Nicholls, 2006) are likely to occur. Good quantitative data are not found in the literature, because such experiments are very difficult. However, it can be concluded that organic systems are very adaptive to climate change thanks to their high multi-level diversity.

C. WEAKNESSES ORGANIC AGRICULTURE IN THE CONTEXT OF CLIMATE CHANGE

52. One major criticism of organic agriculture is its lower productivity. Data shown on energy use and greenhouse gas emissions earlier in this paper indicate that for a few crops and for some farm activities, the relative advantage of organic agriculture vis-à-vis conventional production per land area switches to the contrary when calculated on the crop or livestock produce unit. This is especially true for agronomically difficult crops such as potatoes, grapes and fruits. Pest and disease management problems for these crops have not been solved satisfactorily, and either the yields are low or the energy input is too high.

53. In the case of very intensive cropping systems, especially vegetables with high off-farm input of permitted pesticides and fertilizers, GHG emissions of organic crops seem to be higher for organic crops as well (Bos et al., 2007; Foster et al., 2006). Similar results were found for high input organic arable crops such as those that are common e.g. in the Netherlands (Bos, et al., 2007). These results clearly indicate that such “organic” production systems are not well balanced and use too much energy and nutrients input compared to the phytomedical solutions that have been developed for organic systems (Cooper et al., 2007).

54. Organic production of non ruminants such as poultry and pigs depends on concentrates and high energy feedstuff and, thus, are not likely to have reduced GHG emissions. Some specific veterinary and nutritional problems of non ruminants have not yet been solved and, thus, lead to reduced yields, especially due to ecto- and endoparasites and inappropriate feeding rations (Spoolder et al., 2007).

55. Another critique of organic agriculture concerns soil tillage. Ploughing, an important technique of organic cropping, serves to keep weed infestation low. In temperate zones, organic agriculture is as

efficient as no tillage conventional production in soil conservation and erosion prevention (see section “Organic agriculture and stability and fertility of soils”). During the last decade, ploughing frequencies decreased on many farms due to new machinery and improved crop rotations. Nonetheless it is not yet possible to convert organic arable systems completely to organic no tillage systems because herbicides and soluble nitrogen fertilizers, both crucial for such systems, are banned. In the case of very labile soils in tropical and subtropical regions prone to erosion, organic agriculture needs to be improved as even infrequent ploughing might harm soil stability.

56. These deficits and critical points underline the research and development needs of organic agriculture. Yet, in spite of these issues, organic agriculture is so far the most promising approach for mitigation and adaptation to climate change.

IV. CONCLUSIONS

57. Organic production systems can make important contributions to food supply stability and farmer livelihoods by establishing soil fertility, providing diversity and, therefore, resilience to food production systems in light of the many uncertainties of climate change. In particular, they contribute positively to food stability in terms of fertile and well structured soils, improved water retention, protection of biodiversity with beneficial side-effects on phytomedical stability and nutrients, and water use efficiency.

58. Agricultural production methods specifically adapted to microclimates, production of diverse products, and cropping methods emphasizing soil carbon retention are most likely to withstand climatic challenges and contribute to food stability, particularly in those countries most vulnerable to increased climate change.

59. Organic agriculture is emphatic about making use of farmer and farmer-community knowledge, particularly about farm organization, crop design, manipulation of natural and semi-natural habitats on the farm, use or even selection of locally appropriate seeds and breeds, on-farm preparation of natural plant strengtheners and traditional drugs and curing techniques for livestock, innovative and low budget technology, etc. It is unique in modern agriculture that a food production system is so strongly based on adaptive management.

60. So far, no practical options other than organic agriculture have been proposed to address climate instability. Currently, it is an option which is based and more scientific evidence and field implementation than inexistent or untested technologies such as genetically improved crops that can withstand drought/flood and that can maintain a high resilience in order to cope with unpredictable impacts of climate change.

61. This paper recognizes the deficits of organic agriculture that are mainly related to lower productivity and yield losses. However, the deficits should not be exaggerated. The massively lower yields, those in the range of more than 20 to 30 percent compared to conventional agriculture, occur only in cash-crop-focused production systems and under most favourable climate and soil conditions.

62. Such deficits highlight needs in the current international and national research activities. European countries, leaders in organic agriculture research, spend approximately €60 million per year on specific problems of organic food and farming (Lange, et al., 2006), supplemented with roughly €4

million per annum by the European Commission. This represents less than 1 percent of total food and agriculture research. In order to improve the performance of organic production, more research is needed on:

- soil fertility management and crop growth and health;
- habitat management with improved manipulation and exploitation of diversity at all levels;
- crop breeding programmes focusing on the adaptability of plants to low input situations in soils, in weed competition, and in pest and disease tolerance;
- improved techniques and compounds for plant protection from natural sources;
- organic livestock production breeding concepts and programmes for adaptability to management and environmental stress situations; and
- reduced tillage organic systems;

63. Organic agriculture represents a positive example of how farmers can help mitigate climate change and adapt to its predictable and unpredictable impacts. It could be used as an indicator for allocating national or international development resources to climate change adaptation (e.g. Adaptation Fund) or to measure progress in implementing climate-related multilateral environment agreements (such as already done in 2010 targets of the Convention on Biological Diversity).

V. REFERENCES

Alföldi, T.; Spiess, E.; Niggli, U. & Besson, J.M. 1995. Energiebilanzen für verschiedene Kulturen bei biologischer und konventioneller Bewirtschaftung. Beitr. 3. Wiss.-Tagung okol. Landbau, Kiel. Hrsg. Dewes, T. und Schmitt, L. Wissenschaftlicher Fachverlag, Giessen 1995, 33-36.
Altieri, M. & Nicholls, C. 2006. Agroecology and the search for a truly sustainable agriculture. Berkeley, CA, USA, University of California, 290 pages.

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

Barbera, G. & La Mantia, T. 1995. Analisi agronomica energetica. Filiere atte allo sviluppo di aree collinari e montane: il caso dell'agricoltura biologica. Chironi G Vo. 1 RAISA-University of Palermo.

Bellamy, P.H.; Loveland, P.J.; Bradley, R.I.; Lark, R.M. & Kirk, G.J.D. 2005. Carbon losses from all soils across England and Wales 1978–2003. Nature, 437, 245-248.
Bengtsson, J.; Ahnström, J. & Weibull, A.-C. 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. Journal of Applied Ecology, 42, 261–269.

Berner, A.; Hildermann, I.; Fliessbach, A.; Pfiffner, L.; Niggli, U. & Mäder, P. (2007 submitted) Response of crop yield and soil quality to reduced tillage under organic agriculture conditions. Soil & Tillage Research.

Birkhofer, K.; Bezemer, T.M.; Bloem, J.; Bonkowski, M.; Christensen, S.; Ekelund, F.; Fließbach, A.; Hedlund, K.; Mikola, J.; Robin, C.; Mäder, P.; Setälä, H.; Tatin-Froux, F.; Van der Putten, W.H. & Scheu, S. (submitted 2007): Improving internal nutrient cycling and conservation biological control through long-term organic agriculture. Ecological Applications.

Blaise, D. 2006. Yield, boll distribution and fibre quality of hybrid cotton (Gossypium hirsutum L.) as influenced by organic and modern methods of cultivation. Journal of Agronomy and Crop Sciences 192, 248-256.

Borron, S. 2006. Building resilience for an unpredictable future: how organic agriculture can help farmers adapt to climate change. Food and Agriculture Organization of the United Nations, Rome.

Bos, J.F.F.P.; de Haan, J.J.; Sukkel, W. & Schils, R.L.M. (2007) Comparing energy use and greenhouse gas emissions in organic and conventional farming systems in the Netherlands. In: Niggli, U.; Leifert, C.; Alföldi, T.; Lück, L. and Willer, H, Eds. 2007. Improving Sustainability in Organic and Low Input Food Production Systems. Proceedings of the 3rd International Congress of the European Integrated Project Quality Low Input Food (QLIF). University of Hohenheim, Germany, March 20 – 23, 2007. Research Institute of Organic Agriculture FiBL, CH-Frick, 439 - 442.
Burdick, B. 1994. Klimaänderung und Landbau - Die Agrarwirtschaft als Täter und Opfer. Ökologische Konzepte, Vol. 85, Bad Dürkheim

Caceras, D. 2005. Non-certified organic agriculture: an opportunity for resource-poor farmers? Outlook on Agriculture, 34, 3, p. 135-140.

Cederberg, C; Mattsson, B. 1998. Life cycle assessment of Swedish milk production – a comparison of conventional and organic agriculture. In: Ceuterick, D (ed.) Proceedings of the international conference on life cycle assessment in agriculture, agro-industry and forestry, 3-4 December, Brussels Belgium.

Cooper, J.M.; Schmidt, C.S.; Lueck, L.; Shotton, P.N.; Turnbull, C. & Leifert, C. 2007. Effect of organic, low-input and conventional production systems on yield and diseases in winter barley. In: Niggli, U.; Leifert, C.; Alföldi, T.; Lück, L. and Willer, H, Eds. 2007. Improving Sustainability in Organic Low Input Food Production Systems. Proceedings of the 3rd International Congress of the European Integrated Project Quality Low Input Food (QLIF). University of Hohenheim, Germany, March 20 – 23, 2007. Research Institute of Organic Agriculture FiBL, CH-Frick, 335 - 338.

Cormack, W.F. 2000. Energy use in Organic agriculture Systems (OF0182). Final Project. Report to Ministry of Agriculture, Fisheries and Food, London, UK. http://orgprints.org/8169/

El-Hage Scialabba, N.E. & Hattam, C. 2002. Organic agriculture, environment and food security. Environment and Natural Resources Service Development Department. The Food and Agriculture Organization of the United Nations, Rome.

Ewel, J. (1986) Designing agricultural ecosystems for the humid tropics. Annual Review of Ecology and Systematics, 17, 245-271.

Eyhorn, F.; Ramakrishnan, M. & Mäder, P. (in press 2007) The viability of cotton-based organic agriculture systems in India. International Journal of Agricultural Sustainability.

Fan, T.; Stewart, B.A.; Payne, W.A.; Yong, W.; Luo, J. & Gao, Y. 2005. Long-term fertilizer and water availability effects on ceral yield and soil chemical properties in northwest China. Soil Science Society of America Journal, 69, p 842-855.

Fischer, G.; Tubiello, F.N.; van Velthuizen, H. & Wiberg, D.A. 2006. Climate change impacts on irrigation water requirements: effects of mitigation, 1990-2080. Technological Forecasting and Social Change. In Press.

Fischer, G.; Shah, M.; Tubiello, F.N. & van Velhuizen, H. 2005. Socio-economic impacts on agriculture: an integrated assessment, 1990-2080. Philosophical Transactions of the Royal Society, B, 360, p 2067-2083.

Fließbach, A. & Mäder, P. 1997. Carbon source utilization by microbial communities in soils under organic and conventional farming practice. In: Microbial Communities — Functional versus Structural Approaches. Insam, H., Rangger, A. (eds.). pp 109-120. Springer, Berlin.

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

Foereid, B. & Høgh-Jensen, H. 2004. Carbon sequestration potential of organic agriculture in northern Europe – a modelling approach. Nutrient Cycling in Agroecosystems 68, 13-24.

Forster, C.; Green, K.; Bleda, M.; Dewick, P.; Evans, B.; Flynn, A. & Mylan, J. 2006. Environmental Impacts of Food Production and Consumption: A report to the Department for Environment, Food and Rural Affairs. Manchester Business School. DEFRA, London, 198 pages.

Frossard, D. 2005. In field or freezer? Some thoughts on genetic diversity maintenance in rice. In MR Dove, PE Sajise, and AA Doolittle (Eds.) Conserving Nature in Culture: Case Studies from Southeast Asia. Monograph 54, Yale University Southeast Asia Studies, New Haven.

Fuller, R.J.; Norton, L.R.; Feber, R.E.; Johnson, P.J.; Chamberlain, D.E.; Joys, A.C.; Mathews F.; Stuart, R.C.; Townsend, M.C.; Manley, W.J.; Wolfe, M.S.; Macdonald, D.W & Firbank, L.G. 2005. Benefits of organic agriculture to biodiversity vary among taxa. Biology letters, 1, 431-434.
Gabriel, D. & Tscharntke, T. 2007. Insect pollinated plants benefit from organic agriculture. Agriculture, Ecosystems and Environment, 118, p 43-48.

Gabriel, D.; Roschewitz, I.; Tscharntke, T. & Thies, C. 2006. Beta diversity at different spatial scales: plant communities in organic and conventional agriculture. Ecological Applications, 16, 5, p 2011-2021.

Geier, U.; Frieben, B.; Gutsche, V.; & Köpke, U. 2001. Ökobilanz des Apfelerzeugung in Hamburg - Vergleich integrierter und ökologischer Bewirtschaftung. Schriftenreihe Institut für Organischen Landbau, Verlag Dr. Köster, Berlin, S. 130.

Giller K.E.; Bignell, D.; Lavelle, P.; Swift, M.; Barrios, E.; Moreira, F.; van Noordwijk, M.; Barios, I.; Karanji, N. & and Huising, J. 2003. Soil biodiversity in rapidly changing tropical landscapes: scaling down and scaling up. In Bardgett RD, MB Usher, and DW Hopkins (eds) Biological Diversity and Function in Soils. Cambridge University Press, New York.

Haas, G. & Köpke, U. (1994) Vergleich der Klimarelevanz Ökologischer und Konventioneller Landbewirtschaftung. Studie (H) im Auftrag der Enquetekomission des Deutschen Bundestages Schutz der Erdatmosphäre. D-Karlsruhe, Economica Verlag.

Hatfield J.L.; Sauer, T.J. & Krueger, J.H. 2001. Managing soils to achieve greater water use efficiency: a review. Agronomy Journal, 93, p 271-280.

Hati, K.M.; Mandal, K.G.; Misra, A.K.; Ghosh P.K. & Bandyopdahyay K.K. 2006. Effect of inorganic fertilizer and farmyard manure on soil physical properties, root distribution, and water-use efficiency of soybean in Vertisols of central India. Bioresource Technology, 97, p 2182-2188.

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

Hole, D.G.; Perkins, A.J.; Wilson, J.D.; Alexander, I.H.; Grice, P.V. & Evans, A.D. 2005. Does organic agriculture benefit biodiversity? Biological Conservation, 122, p 113-130.

Holland, J.M. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems and Environment 103, 1-25.

Kaiser, J. 2004. Wounding earth’s fragile skin. Science, 304, p 1616-1618.

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

Kus, J. & Stalenga, J. 2000. Comparison of economic and energy efficiency in ecological and conventional crop production system. In: Alföldi, T.; Lockeretz, W.; & Niggli, N. (eds.) Proceedings 13th International IFOAM scientific conference. Vdf Hochschulverlag, Zürich.

Lange, S.; Williges, U.; Saxena, S. & Willer, H., Eds. 2006. Research in Organic Food and Farming. Reports on organization and conduction of research programmes in 11 European countries. Bundesanstalt für Landwirtschaft und Ernährung (BLE) / Federal Agency for Agriculture and Food BLE, Bonn, Germany.

Lotter, D.; Seidel, R. & Liebhardt, W. 2003. The performance of organic and conventional cropping systems in an extreme climate year. American Journal of Alternative Agriculture 18(3):146-154.

Mäder, P.; Fließbach, A.; Dubois, D.; Gunst, L.; Fried, P. & Niggli, U. 2002. Soil fertility and biodiversity in organic agriculture. Science 296, 1694-1697

Marriott, E.E. & Wander, M.M. 2006. Total and Labile Soil Organic Matter in Organic and Conventional Farming Systems. Soil Sci. Soc. Am. J. 70, 950-959.

Mendelsohn, R. & Williams, L. 2006. “Dynamic Forecasts of the Sectoral Impacts of Climate Change” in Schlesinger et al (eds.) Human-Induced Climate Change: An Interdisciplinary Assessment (forthcoming).

Nemecek, T.; Huguenin-Elie, O.; Dubois, D. & Gaillard, G. 2005. Ökobilanzierung von Anbausystemen im Schweizerischen Acker- und Futterbau, Zürich. 156 p.

Pfiffner, L. & Mäder, P. 1997. Effects of biodynamic, organic and conventional production systems on earthworm populations. Entomological research in organic agriculture. Biological Agriculture and Horticulture 15, 3-10.

Pfiffner, L. & Niggli, U. 1996. Effects of biodynamic, organic and conventional production systems on ground beetles (Col. Carabidae) and other epigaeic arthropods in winter weat. Biological Agriculture and Horticulture 12, 353-364.

Pfiffner, L. 1997. Welchen Beitrag leistet der ökologische Landbau zur Förderung der Kleintierfauna. In: H. Weiger & H. Willer eds. Naturschutz durch ökologischen Landbau. Ökologische Konzepte 95. Bas Dürkheim, Germany

Pfiffner, L.; Merkelbach, L. & Luka, H. 2003. Do sown wildflower strips enhance the parasitism of lepidopteran pests in cabbage crops?. International Organisation for Biological and Integrated Control of Noxious Animals and Plants/West Palaearctic Regional Section Bulletin 26(4):pp. 111-116.
Pimentel, D.; Harvey, C.; Resosudarmo, P.; Sinclair, K.; Kurz, D.; McNair, M.; Crist, S.; Shpritz, L.;

Fitton, L.; Saffouri; R. & Blair; R. 1995. Environmental and Economic Costs of Soil Erosion and Conservation Benefits. Science, Vol. 267, p. 1117-1123.

Pimentel, D.; Hepperly, P.; Hanson, J.; Douds, D. & Seidel, R. 2005. Environmental, energetic, and economic comparisons of organic and conventional farming systems. BioScience 55, 573-582.

Proctor Peter and Gillian Cole, 2002. Grasp the Nettle: Making Biodynamic Farming and Gardening Work. Random House Publishing, New Zealand.

Pulleman, M.; Jongmans, A.; Marinissen, J. & Bouma, J. 2003. Effects of organic versus conventional arable farming on soil structure and organic matter dynamics in a marine loam in the Netherlands. Soil Use and Management 19, 157-165.

Qadir, M.; Sharma, B.R.; Bruggeman, A.; Choukr, R. & Karajeh, F. 2007. Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. Agricultural Water Management, 87, p 2-22.

Quiroga, A.; Funaro, D.; Noellmeyer, E. & Peinemann, N. 2006. Barley yield response to soil organic matter and texture in the Pampas of Argentina. Soil and Tillage Research, 90, p 63-68.

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

Reitmayr, T. 1995. Entwicklungen eines rechnergestützten Kennzahlensystems zur ökonomischen und ökologischen Beurteilung von agrarischen Bewirtschaftungsformen - dargestellt an einem Beispiel. Agrarwirtschaft Sonderheft 147.

Scialabba, N. 2003. Organic Agriculture, The Challenge of Sustaining Food Production While Enhancing Biodiversity, United Nations Thematic Group, Sub-Group Meeting on Wildlife, Biodiversity and Organic Agriculture, Ankara, Turkey, 15-16 April 2003

Shepherd, M.; Pearce, B.; Cormack, B.; Philipps, L.; Cuttle, S.; Bhogal, A.; Costigan, P. & Unwin, R. 2003. An Assessment of the Environmental Empacts of Organic agriculture. (http://www.defra.gov.uk/science/project_data/DocumentLibrary/OF0405/OF0405_909_TRP.doc).

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

Smith, P.; Andrén, O.; Karlsson, T.; Perlälä, P.; Regina, K.; Rounsevell, M. & van Wesemael, B. 2005. Carbon sequestration potential in European croplands has been overestimated. Global Change Biology 11, 2153-2163.

Spoolder, H.A.M.; Maurer, V. & Sundrum, A. 2007. Development of strategies to improve quality and safety and reduce cost of production in organic and “low input” livestock production systems. In: Niggli, U.; Leifert, C.; Alföldi, T.; Lück, L. and Willer, H., Eds. 2007. Improving Sustainability in Organic and Low Input Food Production Systems. Proceedings of the 3rd International Congress of the European Integrated Project Quality Low Input Food (QLIF). University of Hohenheim, Germany, March 20 – 23, 2007. Research Institute of Organic Agriculture FiBL, CH-Frick, 319 - 326.

Steinfeld, H.; Gerber, P.; Wassenaar, T.; Castel, V.; Rosales, M. & de Haan, C. 2006. Livestock's long shadow: environmental issues and options. Food and Agriculture Organisation of the United Nations, Rome.

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

Tengo, M. & Belfrage, K. 2004. Local management practices for dealing with change and uncertainty: a cross-scale comparisons of cases in Sweden and Tanzania. Ecology and Society, 9(3). Available at www.ecologyandsociety.org/vol9/iss3/art4.

Thorup-Kristensen, K. 2007. Effect of crop management practices on the sustainability and environmental impact of organic and low input food production systems. In: Niggli, U.; Leifert, C.;

Alföldi, T.; Lück, L. and Willer, H, Eds. 2007. Improving Sustainability in Organic and Low Input Food Production Systems. Proceedings of the 3rd International Congress of the European Integrated Project Quality Low Input Food (QLIF). University of Hohenheim, Germany, March 20 – 23, 2007. Research Institute of Organic Agriculture FiBL, CH-Frick, 432 - 438.

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

Verhoog, H., Lund, V. & Alrøe, H.F. (2004) Animal Welfare, Ethics and Organic Farming. In: Vaarst, M., Roderick, S., Lund, V & Lockeretz, W. (editors) Animal Health and Welfare in Organic Agriculture. CABI Publishing, Oxon, 73 – 94.

Von Koerber, K. & Kretschmer, J. 2006. Ernährung nach den vier Dimensionen. Wechselwirkungen zwischen Ernährung und Umwelt, Wirtschaft, Gesellschaft und Gesundheit. Ernährung & Medizin 2006; 21: 178–185. Medizinverlage Stuttgart GmbH & Co.

Weibull A.C.; Ostman, O. & Granqvist, A. 2003. Species richness in agroecosystems: the effect of landscape, habitat and farm management. Biodiversity and Conservation, 12, p 1335-1355.

Wetterich, F. & Haas, G. 1999. Ökobilanz Allgäuer Grünlandbetriebe - Intensiv, Extensiviert, Ökologisch. Schriftenreihe Institut für Organischen Landbau, ISBN 3-89574-365-8, Verlag Dr. Köster, Berlin, 94 S.

Willer, H. & Yussefi, M. (eds.) 2007. The World of Organic Agriculture - Statistics and Emerging Trends 2007. International Federation of Organic Agriculture Movements (IFOAM), DE-Bonn and Research Institute of Organic Agriculture, FiBL, CH-Frick.

Wyss, E.; Luka, H.; Pfiffner, L.; Schlatter, C.; Uehlinger, G. & Daniel, C. 2005. Approaches to pest management in organic agriculture: a case study in European apple orchards. Organic-Research.com, May 2005, 33N –36N.

Wyss, E.; Luka, H.; Pfiffner, L.; Schlatter, C.; Uehlinger, G. & Daniel, C. 2005. Approaches to pest management in organic agriculture: a case study in European apple orchards . Beitrag präsentiert bei der Konferenz: "IPM in Organic Systems", XXII International Congress of Entomology, Brisbane, Australia, 16. August 2004; Veröffentlicht in Cab International: Organic-Research.com May 2005, Seite(n) 33N-36N.

Zarea, A.; Koocheki, A. & Nasiri, M. 2000. Energy efficiency of conventional and ecological cropping systems in different rotations. In: Alföldi, T, Lockeretz, W and Niggli, U (eds) 2000. Proceedings 13th International IFOAM scientific conference. Vdf Hochschulverlag, Zürich.

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