II. Organic Agriculture: A Productive Means of Low-carbon and High Biodiversity Food Production

Urs Niggli
Research Institute of Organic Agriculture (FiBL), Switzerland

» Innovative management options, such as organic farming, offer promising opportunities to reconcile the objectives of feeding a rapidly growing human population with minimal adverse impacts on the environment.

» Because of the multiple benefits of organic farming, including the soil sequestration of carbon, the current international efforts to mitigate and adapt to climate change and its consequences provide governments with an ideal platform for fostering a shift towards more sustainable agricultural production.

» Among the policy tools to promote more sustainable agricultural practices, this text highlights the importance of publicly funded research and extension work.

A. Introduction

At present, agriculture faces unprecedented challenges and exciting opportunities globally. The challenges result from the need to secure food supply for a rapidly growing human population, while at the same time having to minimize adverse impacts of agricultural production on the environment. Exciting opportunities relate to new management options, opened up by alternative production targets, technological developments and changing consumer preferences.

A shift towards sustainable agricultural production entails the adoption of comprehensive, more system-oriented strategies. Such strategies include farm-derived inputs and productivity based on ecological processes and functions. Furthermore, it involves the traditional knowledge and entrepreneurial skills of farmers (IAASTD, 2008). Currently, system-oriented sustainable practices include organic farming, low external input sustainable agriculture (LEISA), integrated pest management, integrated production (IP) and conservation tillage. The most consistent approach of these is organic farming. Because of bans or restrictions on the use of many direct control techniques such as pesticides, herbicides, fast acting fertilizers or veterinary medicines, organic farmers rely heavily on preventive and system-oriented practices.

The current international efforts to combat climate change and its consequences provide governments with an ideal platform for fostering a shift towards more sustainable agricultural production. Organic farming generates significant environmental and developmental benefits, including better resource management and more remunerative incomes. In addition, sustainable production of agro-energy and carbon sequestration in soils potentially offers alternative sources of income to farmers. As pointed out in the introductory chapter of this Review, this means that an increase in organic farming at the global level would not only contribute very significantly to general developmental and environmental improvements, but could also make a significant contribution to climate change mitigation and adaptation.

B. Characteristics of organic food and farming systems

Modern organic farm management aims at maximizing the stability and homeostasis of agro-ecosystems. It builds on improving soil fertility through the incorporation of legumes and compost and by strengthening the local recycling of nutrients and organic matter. It uses many preventive measures copied from nature in order to regulate pests and diseases in crops and livestock. Moreover, since it is free from synthetic pesticides and undergoes only gentle and careful processing, using few additives, organic agriculture offers consumers high-quality and healthy food.

The organic concept of how to farm, produce and process foods is globally regulated by a range of very similar standards. Trade is enabled by third-party certification from accredited bodies. In addition, and in order to meet the needs of smallholder farmers and local, low-income consumers, tens of thousands of farms in developing countries are engaged in participatory guarantee systems (PGS). Furthermore, a fast growing number of farmers in developing countries are considered non-certified organic. They deliberately use organic technologies that optimize nutrient flows, and use local resources such as native seeds and traditional knowledge, instead of synthetic chemical pesticides or fertilizers.

Organically farmed and third-party-certified land (including in-conversion areas) amounts to 32.2 million hectares or 0.64 per cent of total global agricultural land area. It is most advanced and widely practiced in European countries (e.g. the Alpine region), Scandinavia and in some Mediterranean countries (where it constitutes 5–15 per cent of the agricultural land area). In developing countries, permanent crops such as coffee, tea, cocoa, coco nuts and olives are increasingly produced according to organic standards in order to satisfy fast-changing consumer habits. The global market for certified organic products has grown to 33.7 billion euros (Willer and Kilcher, 2009).

C. Multifunctional characteristics of organic farming

The unsustainable production of food, feed, fibre and fuel has strongly degraded global ecosystems and the services those systems provide for human survival (Millennium Ecosystem Assessment, 2005). Such ecosystem services include, for example:

- Provision of pure water,
- Recycling of organic matter and nutrients,
- Regulation of climate and weather events by fertile soils,
- Regulation of crop pests and diseases through biodiversity and natural enemies, and
- Pollination of crops by wild animals.

The pace of this degradation has not yet been halted or reversed, although sustainability has become the axiom of agricultural policy. The global loss of fertile soils, for example, is continuing at an annual rate of 10 million hectares (Pimentel et al., 1995). Consequently, an area close to the size of that under arable crop cultivation in Germany disappears by wind and water erosion every year, and is therefore lost for food production, due to unsustainable farming techniques.

No other form of agriculture and food production can claim to offer so many benefits to consumers and to provide such a bounty of public goods as organic farming and food systems. These claims are substantiated by scientific evidence (for a comprehensive review of the literature, see Niggli et al., 2008b; UNCTAD, 2006; Scialabba El Hage and Hattam, 2002; and Stolze et al., 2000). The most notable environmental advantages are summarized below.

1. Biodiversity

Biodiversity is an important driver for the stability of agro-ecosystems (Altieri and Nicholls, 2006), and hence for a continuously stable supply of food. In organic agriculture, biodiversity is both a means and an end. As organic farmers cannot use synthetic substances (e.g. fertilizers, pesticides and chemicals), they depend on carefully restoring the natural ecological balance. At farm level, diversity is practised through various farm activities (e.g. by adding value through processing and direct marketing, or by combining farming with farm schools, visits and adult courses). In the fields, diversity is achieved by multiple crop rotations or agroforestry. Ultimately, organic farms cannot be operated in the long run simply by cultivation that focuses only on economically attractive crops.

The diversity of species on organic farms is predominantly the result of the very specific organic techniques of farmers, including banning the use of pesticides, herbicides and fast-release fertilizers. An organic farm becomes more successful in a diversified landscape where there are sufficient semi-natural landscape elements like hedgerows, fallow ruderal habitats and wildflower strips, which serve as natural means of controlling pests (Zehnder et al., 2007). Soil quality management (e.g. enrichment with compost), tillage practices (e.g. conservation tillage), crop rotation and intercropping are important additional measures, aimed at lowering the risk of pest and disease outbreaks. It is therefore in the economic interest of organic farmers to enhance diversity at all levels, because organic weed, pest and disease management would fail without high diversity.

Comparative biodiversity assessments on organic and conventional farms reveal a 30 per cent higher species diversity and a 50 per cent greater abundance of beneficial animals in organic fields (Bengtsson, Ahnstrom and Weibull, 2005; Hole et al., 2005). The higher biodiversity applies to many different taxonomic groups, including micro-organisms, earthworms, insects and birds (Hole et al., 2005). In regions where the number of organic farms has increased, the diversity and abundance of bees has grown considerably, which contributes to the pollination of crops and wild plants over larger areas (Rundlöf, Nilsson and Smith, 2008).

2. Lower negative environmental impacts

The high dependence of traditional farming on chemical fertilizers, herbicides and pesticides has caused considerable environmental damage. Due to the ban of chemical fertilizers on organic farms, 35 to 65 per cent less nitrogen leaches from arable fields into soil zones where it could degrade ground and drinking water quality (Drinkwater, Wagoner and Sarrantonio, 1998; Stolze et al, 2000). Other nutrient elements like potassium and phosphorous are not found in excessive quantities in organic soils, which increases their efficient use (Mäder et al., 2002). Since synthetic herbicides and pesticides are not applied in organic farms, they cannot be found in their soils, surface and groundwater.

3. Stable soils – less prone to erosion

Fertile soils with stable physical properties have become the top priority of sustainable agriculture. Essential conditions for fertile soils are vast populations of bacteria, fungi, insects and earthworms, which build up stable soil aggregates. There is abundant evidence from European, United States, Australian and African studies that organic farms and organic soil management enhance soil fertility. Compared to conventionally managed soils, organically managed ones show higher organic matter contents, higher biomass, higher enzyme activities of microorganisms, better aggregate stability, improved water infiltration and retention capacities, and less water and wind erosion (Edwards, 2007; Fliessbach et al., 2007; Marriott and Wander, 2006; Pimentel et al, 2005; Reganold, Elliot and Unger, 1987; Reganold et al, 1993; Siegrist et al., 1998). The fact that organic farmers use a plough periodically in order to bury weed roots and seeds does not render their soils more prone to erosion (Teasdale et al., 2007; Müller et al., 2007).

4. Carbon sequestration

Organic farmers use different techniques for building up soil fertility. The most effective ones are fertilization by animal manure, by composted harvest residues and by leguminous plants as (soil) cover and (nitrogen) catch crops. Introducing grass and clover leys into the rotations as feedstuff for ruminants and diversifying the crop sequences, as well as reducing ploughing depth and frequency, also augment soil fertility. All these techniques also increase carbon sequestration rates in organic fields. Long-running field experiments in the United States and Europe reveal significant carbon gains in organically managed plots, whereas in the conventional or integrated plots soil organic matter is exposed to losses by mineralization (table 7). The average difference in the annual sequestration rate between the best organic and the worst conventional management in four field trials in Germany, Switzerland and the United States amounted to 590 kg of carbon (or 2.2 tons of CO_2) per hectare of arable land. A further increase of carbon capture in organically managed fields can be measured by reducing the frequency of soil tillage. In the Frick experiment in Switzerland (table 7) the annual sequestration rate was jacked up to 3.2 tons of CO_2/hectare per year by not turning the soil with a plough, but by preparing the seedbed by loosening the soil with a chisel plough instead.

5. More efficient use of nitrogen, less greenhouse gas emissions on organic farms

In agro-ecosystems, mineral nitrogen in soils boosts crop productivity. Crop productivity has increased substantially through the use of heavy inputs of soluble fertilizers – mainly nitrogen – and synthetic pesticides. However, only 17 per cent of the 100 Mt of industrial nitrogen produced in 2005 was taken up by crops. The remainder was lost to the environment (Erisman et al., 2008). Between 1960 and 2000, the efficiency of nitrogen use for cereal production decreased from 80 per cent to 30 per cent. High levels of reactive nitrogen (NH_4, NO_3) in soils may contribute to the emission of nitrous oxides, and are a major source of agricultural emissions. The efficiency of fertilizer use decreases with increasing fertilization, because a large part of the fertilizer is not taken up by the plant but instead emitted into water bodies and the atmosphere.

In organic agriculture, the ban on industrially produced nitrogen and the reduced livestock density per hectare considerably decrease the concentration of easily available mineral nitrogen in soils, and thus, N_2O emissions. Furthermore, diversifying crop rotations with green manure improves soil structure and diminishes N_2O emissions. Soils managed organically are more aerated and have significantly lower mobile nitrogen concentrations, which further reduces N_2O emissions. As a result, the limited availability of nitrogen in organic systems requires careful, efficient management (Kramer et al., 2006). In a long-running field trial in Switzerland, lasting 32 years, the total nitrogen input into an organic arable crop rotation over 28 years was 64 per cent of the integrated/conventional rotation; the

Table 7. Comparison of soil carbon gains/losses in different farming systems in field experiments

Field trial	Components compared	Carbon gains (+) or losses (-) (kg. of carbon/ha per year)	Relative yields of respective crop rotations (%)
DOK[a] Experiment, Research Institute FiBL and Federal Research Institute Agroscope (Switzerland) (Mäder et al., 2002; Fliessbach et al., 2007) Running since 1977	Organic, with composted farmyard manure	+ 42	83
	Organic, with fresh farm-yard manure	- 123	84
	Integrated production, with fresh farmyard manure and mineral fertilizer	- 84	100
	Integrated production, stockless, with mineral fertilizer	- 207	99
SADP,[b] USDA-ARS, Beltsville, Maryland (United States) (Teasdale et al., 2007) Running 1994 to 2002	Organic, reduced tillage	+810 to + 1 738	83
	Conventional, no tillage	0	100
Rodale FST, Rodale Institute, Kurtztown, Pennsylvania (United States) (Hepperly et al., 2006; Pimentel et al., 2005) Running since 1981	Organic, with farmyard manure	+ 1 218	97
	Organic, with legume-based green manure	+ 857	92
	Conventional	+ 217	100
Frick[c] Reduced Tillage Trial, Research Institute FiBL, (Switzerland) (Berner et al., 2008) Running since 2002	Organic, with ploughing	0	100
	Organic, with reduced tillage	+ 879	112
Scheyern[d] Experimental Farm, University of Munich, Germany (Rühling et al., 2005), Running since 1990	Organic	+ 180	57
	Conventional	- 120	100

Note: Data given as C; for conversion into CO_2 multiply by 3.67.

[a] In the DOK trial, all plots started with exactly the same soil organic matter (SOM) content. In the organic treatment where the farmyard manure was applied as compost, the SOM slightly increased, whereas in the organic and integrated systems with fresh manure, the SOM slightly decreased. The integrated treatment with mineral fertilizers (stockless) showed a significant annual carbon loss. The difference between the best organic practice and the stockless integrated production was 249 kg of carbon/ha per year. DOK = bio**D**ynamic, **O**rganic and **C**onventional farming systems.

[b] SADP = Sustainable Agriculture Demonstration Project of the United States Department of Agriculture.

[c] In the Frick trial, only organic treatments are compared (ploughing versus reduced tillage). No conventional treatment is part of the comparison.

[d] In Scheyern, the experimental farm is separated into two parts: a conventional and an organic one. The organic rotation is situated on poorer soils, which explains the bigger differences in yields.

total organic yields over the same period were 83 per cent of the conventional ones. This demonstrated that organic farms use nitrogen in a more efficient and less polluting way (Mäder et al., 2002).

In a simplified scenario, a conversion of global agriculture to organic farming would reduce the greenhouse gas (GHG) emissions of the agricultural sector considerably and make agriculture almost GHG neutral (Niggli et al., 2009). GHG emissions in CO_2 equivalents, stemming from the production and application of nitrogen fertilizers from fossil fuel, are estimated to be 1,000 million tons (2 per cent of total global GHG emissions). These emissions would not occur using an organic approach, so that the GHG emissions of agriculture would be reduced by roughly 20 per cent. Another 40 per cent of the GHG emissions of agriculture could be mitigated by sequestering carbon into soils. For the assumption we calculate a modestly increased sequestration rate of 100 kg of carbon/ha per year for pasture land and 200 kg of carbon/ha per year for arable crops (see table 6). By combining organic farming with reduced tillage, the sequestration rate can be increased to 500 kg of carbon/ha per year in arable crops as compared to ploughed conventional cropping systems. This would reduce GHG emissions by another 20 per cent.

The scenario described above would mitigate total global GHG emissions by 6 to 9 per cent (from 2008 levels). In an in-depth study for Austria, a conversion to organic farming was modelled to reduce the Austrian GHG emissions by 3 per cent (Freyer and Dorninger, 2008). With the much higher sequestration rates as measured in the Rodale experiment in Pennsylvania (table 7), LaSalle and Hepperly (2008) estimated the potential for mitigation from organic agriculture to be 25 per cent of the total GHG emissions of the United States. This spread of the mitigation potential of different scenarios demonstrates that organic farming is an important option in a multifunctional approach to climate change.

D. Organic farms are well adapted to climate change

As a result of climate change, agricultural production is expected to face less predictable weather conditions than experienced during the last century. South Asia and Southern Africa, in particular, are expected to be the worst affected by negative impacts on important crops, with possibly severe humanitarian, environmental and security repercussions (Lobell et al., 2008).

Thus the adaptive capacity of farmers, farms and production methods will become especially important to cope with climate change. As unpredictability in weather events will increase, robust and resilient farm production will become more competitive and farmers' local experiences will be invaluable for permanent adaptation. Organic agriculture stresses the need to use farmer and farmer-community knowledge, particularly about such aspects as 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 fertilizers, natural plant strengtheners and traditional drugs and curing techniques for livestock, as well as innovative and low-budget technologies. Tengo and Belfrages (2004) describe such knowledge as a "reservoir of adaptations".

Techniques for enhancing soil fertility help to maintain crop productivity in case of drought, irregular rainfall events with floods and rising temperatures. Soils under organic management retain significantly more rainwater thanks to the "sponge properties" of organic matter. Water infiltration capacity was 20 to 40 per cent higher in organically managed *loess* soils in the temperate climate of Switzerland when compared to conventional farming (Mäder et al., 2002). Pimentel et al. (2005) estimated the amount of water held in the upper 15 cm of soil in the organic plots of the Rodale experiment at 816,000 litres/ha. This water reservoir was most likely the reason for higher yields of corn and soybean in dry years. During torrential rains, the rate of water capture in the organic plots was approximately 100 per cent higher than in the conventional ones (Lotter, Seidel and Liebhardt, 2003). This significantly reduced the risk of floods, an effect that could be very important if organic agriculture were practiced over much larger areas. Similar findings, that organic farming improves the physical properties of soils and therefore the drought tolerance of crops, were made in on-farm experiments in Ethiopia, India and the Netherlands (Pulleman, et al., 2003; Eyhorn, Ramakrishnan and Mäder, 2007; Edwards, 2007).

The capacity of farms to adapt to climate change depends not only on soil qualities, but also on their diversity of species and diversification of farm activities. The parallel farming of many crop and livestock species greatly reduces weather-induced risks. Landscapes rich in natural elements and habitats buffer climate instability effectively. New pests, weeds and diseases – the results of global warming – are likely to be less invasive in natural, semi-natural and agricultural habitats that contain a high number and abundance of species (Zehnder et al., 2007; Altieri, Ponti and Nicholls, 2005; Pfiffner, Merkelbach, and Luka, 2003).

E. Can organic farming feed the world?

The fast growing human population gives rise to the crucial question as to whether organic farming could feed the world. The indisputable advantages of organic farming in delivering public goods and services shrink if too much land is needed to produce food. The question of the productivity of organic systems was addressed by a group of scientists led by Professor Ivette Perfecto at Michigan University. Analysing the yields of hundreds of plot and farm experiments, and comparing organic and conventional farming, they concluded that organic agriculture could feed considerably more people than the current world's population of 6.7 billion (Badgley et al., 2007). According to other review papers, yields of organic crops may be reduced by 30 to 40 per cent in intensively farmed regions under best geo-climatic conditions. In less favourable crop growing regions, organic yields tend to match conventional ones. In the context of subsistence agriculture, and in regions with periodic disruptions of water supply (droughts, floods), organic agriculture is competitive vis-à-vis conventional agriculture, and often superior with respect to yields. The Capacity Building Task Force (CBTF) on Trade, Environment and Development of UNEP and UNCTAD recently published the results of numerous case studies showing that, in comparison to traditional subsistence farming, yields were more than double (with a mean of 116 per cent) by applying organic farming practices, especially through more diverse crop rotations, integration of legumes and through closing the cycles of plant nutrients and organic matter on farms or in regions. (For data on the competitiveness and performance of organic agriculture see, for example, Badgley et al., 2007; Halberg et al., 2006; UNEP-UNCTAD, 2008b.)

The picture painted by many critics of organic farming, that it is unproductive and technophobic, is misleading. In many cases, organic farming is very productive. In addition, organic farming systems use many modern technologies like bio-pesticides, natural fertilizers and parasitic or predatory insects or microorganisms in a smart way. Even in the case of highly controversial technologies like genetic engineering, organic farming uses selectively some tools (e.g. molecular markers in breeding or in the diagnosis of pest and disease incidence in crops and livestock). Actually, there is no contradiction between organic rules and cutting-edge technologies. Technologies are banned in cases where risks are increased, where precaution is necessary and prevention offers better solutions. The ban of synthetic nitrogen showcases this strategy: organic farmers manage nitrogen derived from organic matter, soils and legumes more carefully and with fewer losses, as nitrogen is scarce. As a result, organically managed soils are more fertile and resilient to diseases and drought. This also makes organic farmers independent of rising oil prices and imported synthetic inputs, and reduces the environmental impact of farming considerably (Granstedt, 2006; Crews and Peoples, 2004).

The overall concept of organic agriculture offers ample scope to increase the productivity of farms on the basis of eco-functional intensification. In conventional farming, “intensification is understood primarily as using a higher input of nutrient elements and of pesticides per land unit. It also means more energy (direct for machinery and indirect for inputs). Finally, it focuses on better exploiting the genetic variability of plants and animals; to do so, all available breeding techniques, including genetic engineering, are used” (Niggli et al., 2008b). Eco-functional intensification on the other hand “means, first and foremost, activating more knowledge and achieving a higher degree of organization per land unit. It intensifies the beneficial effects of ecosystem functions including biodiversity, soil fertility and homeostasis. It uses the self-regulating mechanisms of organisms and of biological or organizational systems in a highly intensive way. It closes material cycles in order to minimize losses (e.g. compost and manure). It searches for the best match between environmental variation and the genetic variability of plants and livestock” (Niggli et al., 2008b).

As in all food and farming systems, progress is the result of scientific research and educational activities. Technology and knowledge which is well adapted to organic food chains is not among the priorities of public and private funding. Thus it is completely underdeveloped in most parts of the world. Even in Europe, where organic farming research is the most advanced, annual spending for organic food and farming research is less than 80 million euros (Niggli et al., 2008b) – probably less than 1 per cent of private and public research and development (R&D) budgets.

F. Conclusions

Recently, the CBTF made 35 recommendations to developing-country governments on how they could promote their organic agricultural sector (UNEP-UNCTAD CBTF, 2008a). These recommendations are globally applicable, as comparable institutional, economic and political obstacles to organic farming are common in all countries. Many of them are low-cost measures which can be integrated into existing policies and implemented by existing organizations or units.

In the author’s view, the most important actions concern the shift of publicly funded research and extension work towards a focus on sustainable ecosystem-based agriculture. This will create many novel solutions to bottlenecks that reduce the productivity of organic and near-organic sustainable food and farming systems. Organic food chains and organic production systems have to be analysed using cutting-edge scientific approaches, and their impact on landscapes, rural areas and society should be modelled. Governments should give incentives to scientists, teachers and advisers to value farmers’ knowledge and support farmer-to-farmer exchanges. Recent studies show considerable financial and non-financial benefits where cooperation is high at all levels of food chains (Stolze et al., 2007).

Third-party certification is an important tool for accessing international markets and for creating trust in anonymous producer-consumer situations. In addition, governments should encourage/promote PGS for local markets, mainly for smallholder farmers and low-income consumers in developing countries. Such systems strengthen farmer-consumer cooperation, and instil a sense of responsibility and cooperation (and mutual control) among farmers (UNCTAD, 2008). The International Federation of Organic Agriculture Movements (IFOAM), as the pioneer in organic regulations and criteria-setting for certification, should promote PGS as it can underpin organic agriculture's role in addressing poverty in a sustainable way.

Many governments give false incentives to agriculture (e.g. by subsidizing agrochemicals, mineral fertilizers, fuels or specific crops like maize). This makes organic techniques (e.g. managing manure and waste in a proper way, growing legumes or diversifying crop rotations) economically less competitive. These ill-conceived incentives should be revised or abandoned, as they also have adverse environmental impacts. Specific social objectives or hardships could be better addressed through direct income support measures.

International organizations should increase their efforts at facilitating South-South cooperation and knowledge exchange at all levels of organic food chains. And finally, national and international organic farmers' organizations should become more actively involved in developing innovation. Much effort has gone into the consistent implementation of a pioneering idea through standardization, harmonization and market development over the last 15 years. At the same time, there is a certain backlog in organic agriculture. The combination of organic farming and reduced tillage, for instance, would offer huge carbon sequestration options and could become the basic requirement for GHG credit schemes.

Organic agriculture is more than a less polluting form of food production. It basically raises questions about the food habits of people in the developed and emerging regions of the world. As organic farms have lower livestock densities because of their environmental impact, and because they ban factory farms more land is available for vegetable production with a seven times higher calorie output for human nutrition. Consequently, organic agriculture inculcates an eating pattern involving less meat and dairy foods and a higher proportion of vegetables and fruits. Good for health thus becomes good for the environment and good for global food security!