Organic farming’s contribution to climate change and agricultural sustainability

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Introduction

Climate change and sustainability have risen rapidly up the political agenda. The twin challenges of global warming and peak oil present stark choices for the future development – and even survival - of civilisation. The supply of food and water are central to this survival: we need to ensure that farming systems are sustainable in terms of their resource use and impacts, and capable of adapting to future challenges.

It is often claimed that organic farming is sustainable farming, but the claims are not universally or even widely accepted. Indeed, many forms of ‘sustainable agriculture’ are promoted by governments and large corporations, such as Unilever, that do not even recognise the relevance of organic farming. So what is the real relevance of organic farming in this context? What does it currently achieve and where does it have potential to do more? This paper aims to examine these issues.

What is agricultural sustainability?

The idea of sustainability is often presented as consisting of three dimensions: economic, environmental and social, but for agriculture these dimensions cover a wide range of issues, including: resource use sustainability (including soil, water, energy, minerals and genetic resources); environmental pollution (including greenhouse gas emissions, nitrate leaching, pesticides etc.); biodiversity and ecosystem services; food security (including quantity, quality and safety); social impacts (including occupational health and safety, employment and working conditions, rural communities and culture) and financial viability (to provide appropriate returns to the people who do the work).

Once one starts to look at all these issues, it becomes clear that sustainability is about a complex mix of objectives, where the achievement of all simultaneously is unlikely, if not impossible. There will at some point have to be trade-offs between objectives, and different people will prioritise the individual objectives differently. So it is not surprising that there is no agreement on what sustainable agriculture is. The idea of a perfectly sustainable agriculture is therefore an illusion, unachievable. All forms of agriculture, including organic farming, will have some negative impacts somewhere. The existence of weak points, however, doesn’t invalidate their contribution to agricultural sustainability. What matters is their *relative* overall sustainability – how do the contributions of different farming systems to all of the objectives compare?

The hypothetical radar or web diagram below illustrates the point – one system may perform very well with respect to one objective, but relatively poorly on others, while another system may not score so well on that one objective, but the higher score on others gives a better sustainability rating overall. No system is likely to score a perfect 10 out of 10 on all points.

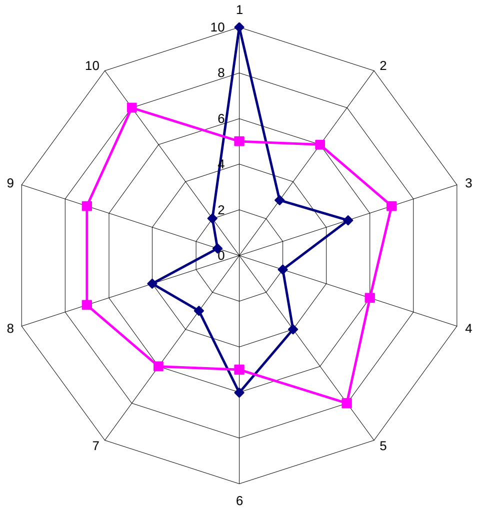

Fig. 1: Hypothetical comparison of outputs by different systems

Why is organic farming relevant?

Organic farming aims to be more sustainable by adopting principles of organism and system health, ecology, fairness and care (IFOAM, 2005). These include ideas of mixed farming, resource self-sufficiency, self-regulation of pest and diseases within agro-ecosystems, and waste minimisation. Organic standards and regulations have been developed to help realise these ideas in practice, with guidance on specific permitted or restricted practices that may be used. In particular, restrictions on the use of fertilisers, pesticides and other external inputs, and encouragement to use rotations and organic manures to build soil fertility, form part of these guidelines.

It is clear that any of the practices adopted by organic producers, taken individually, could be (and are) practiced by any farmer. What makes a difference is that specific practices are typically rather than occasionally adopted by organic producers, as well as the particular combination of practices that is promoted in organic farming.

What is the role of standards?

Organic production standards in the European Union are legally defined, currently by EC Reg. 2092/91. They specify prohibited and permitted practices that organic producers may adopt. They have been developed to define a distinct production process in order to support the specialist market for organic products, protecting consumers and *bona fide* producers. The existence of a premium market helps to maintain the financial sustainability of organic farms, by compensating for the lower output that often results from restricting practices in pursuit of broader health and sustainability goals.

However, because standards are targeted at the market, they may emphasise issues that are of greater priority to consumers, such as non-use of pesticides, and may be less focused on specific environmental outputs. In fact, organic farming standards have been criticised because they do not contain specific environmental conditions that might be expected in agri-environment schemes. Despite this, it is important to acknowledge that many of the environmental and sustainability benefits that organic farming delivers may be an indirect result of the standards, rather than specifically provided for by them. For example, organic farming may support more farmland birds, because the prohibition of herbicides leads to a higher proportion of spring cereals in the rotation to help with weed control, which in turn provides overwintering stubbles to support birdlife.

It may also be that the premium market and strict regulations are not essential to the delivery of environmental benefits from organic farming. Few other agri-environmental schemes, such as Tir Gofal, connect to the marketplace, and some countries such as Sweden operate agri-environment schemes for organic farming without any link to certification and marketing of organic products. This could help resolve some of the tensions between the different expectations of policy makers interested in environmental outputs, and consumers with specific food quality and safety concerns. Despite this, the strong links to the consumer are seen as a significant advantage of organic farming by both producers and policy makers (WAG, 2007).

Assessing the evidence

While organic standards set out principles and practices that are believed to contribute to achieving the overall health and sustainability goals of organic farming, they do not necessarily guarantee delivery of the outcomes. Organic farming, like agriculture in general, is not homogeneous. There are many different types and intensities of organic farming systems (ranging from hill farms to intensive market gardens) and there are many different individuals involved with differing skills, experience and priorities. This diversity will of course result in widely differing impacts on the environment and sustainability, with the benefits in some cases much lower than in others, and even negative impacts in some situations.

It is important therefore to take a close look at the evidence of actual impacts as well the theoretical outcomes. However, it is impossible in a review of this type to cover every eventuality, so a generalised overview of the evidence is unavoidable. Where possible, however, issues specific to particular types of organic farming are highlighted.

Impacts on climate change

Organic farming, by using less fossil energy and building soil organic carbon levels can make a direct contribution to mitigating climate change.

Fossil energy use and CO_2 emissions

The issues of fossil energy use, in the context of the sustainability and Peak Oil debates, and climate change, resulting from greenhouse gas emissions, are closely linked as fossil energy is the major source of carbon released into the atmosphere. They are two sides of the same coin: evidence on energy use can also be used to draw conclusions on climate change impacts.

Overall organic farming uses less fossil energy on a per hectare and a per unit food produced basis than intensive, conventional farming systems. This has been demonstrated in a wide range of research projects since the 1970s. The 1973 oil crisis made energy use in agriculture an important topic for the first time (e.g. Leach, 1976; Lockeretz, 1977 and Pimentel, 1980). More recently, reviews by Stolze et al. (2000), Scialabba and Hattam (2002), Shepherd et al. (2003) and Pimentel (2006) have reinforced the findings of the early studies.

The main reasons for the reduced fossil energy inputs in organic farming on a per hectare basis are the restrictions on the use of synthetic nitrogen fertilisers, herbicides and pesticides, all of which require significant fossil energy inputs for their manufacture and distribution although in some countries such as Norway, hydro power is also used for fertiliser manufacture.

These lower energy inputs may be offset by increased energy needed for cultivations, particularly for weed control. Leake (1995), for example, illustrates the impact that intensive cultivations can have on energy in organic crop production (Table 2). Research comparing organic with integrated and conventional farming systems in long term trials (Alfoeldi et al., 1995, see Fig. 2) has shown that energy inputs for other production practices are very similar between the systems, even taking account of increased mechanical cultivations for weed control.

Table 1: Relative energy use in organic and conventional farming

Study	*Country*	*Product*	*Energy use (org. as % of conv.)*	
			per ha	*per unit*
Mercier (1978)	France	Wheat	50	55-60
Klepper et al. (1977)	United States	All crops	-	40
USDA (1980)	United States	Cereals	42-85	50-87
Vine & Bateman (1981)	England/ Wales	Farm	25-100	50-100
Pimentel et al. (1983)	United States	Maize	58	59
		Wheat	68	72
		Potatoes	57	114
Kaffka (1984)	Germany	Wheat	20	26
Harwood (1985)	United States	All crops	50-90	50-80
Haas & Koepke (1994)	Germany	All crops	36	-
		Wheat	35	57
		Potatoes	54	81
Alfoeldi et al. (1995a)	Switzerland	Wheat	59	67
		Potatoes	72	107
Reitmayr (1995)	Germany	Wheat	49	79
		Potatoes	73	129
Barbera & La Mantia (1995)	Italy	Citrus	57	67
		Olives	45	55
Kalk et al. (1996)	Germany	Farm	66.5-89	-
Edwards-Jones & Howells (1997)	Scotland	Potatoes	29	24
		Wheat	51	70
		Barley	48	65
Lampkin (1997)	Wales	Milk	70	87
Refsgaard et al. (1998)	Denmark	Cereals	-	87
		Forage	-	32
		Milk	-	84
Cederberg & Mattson (1998)	Sweden	Milk	77	85
Wetterich & Haas (1999)	Germany	Milk	31	46
Cormack & Metcalfe (2000)	England	Wheat	40	70
		Potatoes	55	86
		Carrots	41	127
		Cabbage	53	65
		Onion	69	93
		Calabrese	30	60
		Leeks	40	-
Geier (2001)	Germany	Apples	91.5	123
Williams et al. (2006)	England	Wheat	-	71
		Oilseed	-	75
		Potatoes	-	102
		Beef	-	65
		Sheep	-	80
		Milk	-	62
		Pigs	-	87
		Eggs	-	114
		Poultry	-	132

Table 2: Comparison of energy inputs (kWh/t) for machinery and fertiliser manufacture for wheat production from different systems (Leake, 1997)

	Machinery	*Fertiliser*	*Total*
Organic	200	0	200
Integrated	67	211	278
Conventional	78	296	374

Lower levels of fossil energy use per hectare may also be offset by lower yields, potentially resulting in higher energy inputs per kg of food produced. Many of the studies reported in Table 1, however, show that the improved energy efficiency of organic farming can be maintained despite lower yields. For some crops such as potatoes, the yield differences are sufficiently large to result in higher energy inputs per kg for organic crops. This can also apply in the case of crops like carrots if flame weeding is used extensively.

Similar issues can be identified in ruminant livestock production, due to the energy savings associated with reliance on clover-grass leys and high forage/low cereal diets, as the results in Table 1 illustrate. Energy inputs per litre milk or kg meat produced, however, are also affected by stocking rates, which depend on the extent to which farms rely on purchased feed: the energy required to produce this feed on 'borrowed acres' should also be taken into account.

Pigs and poultry comparisons are more complex due to reliance on cereals, longer finishing periods and free range production, but few direct studies have been carried out. Williams et al. (2006) estimate that organic poultry production is more energy intensive than conventional (Table 1), but when compared with free range, the energy input is more similar (5-9% higher).

Energy output/input ratios are an important indicator of the net effectiveness of agriculture in capturing solar energy to feed human populations (Table 3). The higher the ratio the better – tropical subsistence farming typically achieves ratios between 10 and 40, 70 for crops like cassava. Any value less than one indicates that more energy is consumed than produced.

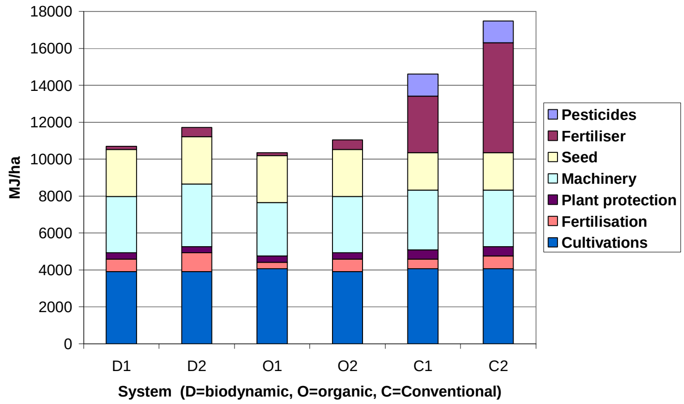

Fig. 2: Direct and indirect energy use for different systems at two fertiliser levels in the DOC long-term comparison trial (average of 6 years; Alfoeldi et al., 1995b)

This is particularly the case for fishing fleets, but UK agriculture overall achieved less than 0.5 already in the 1960s, and caged birds and poultry were around 0.1 (Leach, 1976). The low values for livestock products, particularly those reared intensively with high cereal inputs, illustrates the need to consider low meat diets and producing livestock in a manner more complementary to human food requirements, as part of any strategy to reduce fossil energy use.

Table 3: Energy output/input ratios for selected crops

Source	*Product*	*Conv.*	*Org.*
Leach (1976)	Wheat	3.5	-
	Maize	2.8	-
	Potatoes	2.6	-
	Milk	0.4	-
	Poultry	0.1	-
Pimentel (2006)	Wheat	2.1	-
	Maize	5.1	7.7
	Soya	3.2	3.8

Soil organic matter

Arable/mixed organic farms restore soil organic matter levels and store carbon.

Soil organic matter is particularly important for organic farming, soil conservation and climate change. Soil organic matter helps retain moisture and nutrients, maintain soil structure, reduce erosion and acts as a carbon sink. Soil organic matter also provides an energy source for the soil eco-system.

This is essential for the release of nutrients for plant growth, in particular the mineralisation of nitrogen and release of phosphate bound to soil particles. Organic management practices emphasise careful mechanical cultivation, rotations incorporating fertility building phases and the return of organic crop residues, green manures and livestock manures. These practices are particularly important in the context of climate change.

The addition of mineral fertilisers, especially nitrogen, to the soil not only provides nutrients for crop growth, but also for soil microbes and other organisms. These organisms can then grow and reproduce, but need an energy source to do this, which is typically derived from the breakdown of plant residues and soil organic matter, releasing CO_2 in the process. Without the replenishment of organic matter, this will lead to a decline in organic matter levels and net CO_2 loss into the atmosphere. Organic standards significantly restrict the use of synthetic nitrogen fertiliser and other high-solubility mineral fertilisers. They also encourage the use of organic manures to recycle nutrients. With organic manures, the energy source for the soil microbes is supplied with the nutrients, so that soil reserves do not need to be utilised.

While the production of crops with mineral fertilisers will generate some crop residues (straw, roots etc.) to compensate for organic matter losses, the effect is relatively small for most annual arable crops such as wheat, barley and oilseed rape. Organic farmers have to rely on a fertility building phase in their crop rotations. Not only does this provide the nitrogen crops need, as well as weed, pest and disease control benefits, but it also replenishes soil organic matter potentially leading to long term increases in carbon storage in soils under organic management. For comparison, the residual root biomass is 5-8 t dry matter per hectare from clover leys, compared with 0.5-1.5 t DM/ha from annual arable crops (Lampkin, 1990). Some long term comparisons of different farming systems (e.g. the Rodale experiment in the US: Pimentel et al., 2005) have shown significant increase in soil organic carbon. However, not all studies support this. In particular, the Swiss DOC comparison (Maeder et al., 2002; Fliessbach et al., 2007) shows a decline in soil organic carbon over a 21 year period, with few significant differences between systems. A key limitation of this comparison, however, is that the same rotation features in each system.

There is an argument that the increased requirement for mechanical cultivation for weed control in organic farming can be a negative influence on soil organic matter levels. Mechanical cultivation has the effect of aerating the soil, increasing the oxygen supply to microbes, stimulating soil organic matter mineralisation and CO_2 release. Some authors argue that this makes minimum tillage systems relying on herbicides to kill off remaining plant vegetation before reseeding more sustainable and climate friendly. It is possible to reduce the need for mechanical weed control in organic farming through rotation design and through adapted minimum tillage systems without herbicides. More importantly, there is now research evidence from long term comparison trials in the US (Teasdale et al., 2007), that the combination of restrictions on mineral fertilisers, increased use of organic manures and the fertility building phase in organic rotations actually outweighs the effect of mechanical cultivation and generates a better overall effect on soil organic carbon than conventional no-till systems.

In much of Wales, particularly in the hills and uplands, high rainfall, poor drainage and relatively low temperatures have combined to slow the rate at which organic matter breaks down, so that soils typically have high organic matter levels. They are referred to as organic soils if they have more than 12-18% organic matter depending on clay content (e.g. peaty soils). Organic soils should not be confused with organically certified or managed soils. These soils represent a huge reserve of CO_2 that could potentially be released into the atmosphere. Drainage and cultivation are important triggers for this, which should be avoided. Organic standards and Environmental Impact Assessment requirements for cultivation of permanent grassland place some restrictions on what may be done, but there is a case for further action (WAG, 2007). Reduction in organic matter levels in organic soils might also be encouraged by nitrogen deposits from atmospheric pollution as well as lower rainfall and higher temperatures resulting from climate change, which all have the potential to increase microbial activity.

Methane

Although significant attention is focused on carbon dioxide as the greenhouse gas emitted in largest quantities, methane has much bigger climate change impacts and is particularly associated with livestock production. About 75% of methane on farms is emitted directly from ruminant animals, (Shepherd et al., 2003).

There have been few direct comparisons of methane generation between organic and conventional production (Stolze et al., 2000). Two recent studies from Switzerland (Nemecek, 2006) and the UK (Williams et al. 2006) have used life cycle analysis methods to estimate the global warming potential (GWP) from organic and conventional systems. This approach converts the more damaging methane and other emissions into CO_2 equivalents. Williams et al. (2006) found that global warming potential was similar for both organic and conventional crops, with a slight tendency for organic to be lower. Organic milk and beef enterprises, however, were estimated to be about 20% higher, although organic sheep were much lower. As with energy inputs, poultry GWP values were higher for organic.

One recent study of conventional and organic milk production (Table 4) has shown more potential to reduce overall greenhouse gas emissions. Though still showing the tendency for higher methane emissions, these are offset by lower nitrous oxide emissions (see next section).

These results indicate a need for further research to get a better understanding of the methane problem. To do this, it is necessary to consider effects at several levels, including the individual animal, individual farm and whole sector.

Table 4: Combined greenhouse gas emissions from organic & conventional milk production (Allen et al., 2007)

System	*Conv. average*	*Conv. top 25%*	*Org. average*	*Org. top 25%*
g CO_2 equivalent per litre milk	907	745	828	705
% from CO_2	23	25	21	22
% from CH_4	52	55	69	68
% from N_2O	25	20	10	10

As far as the individual animal is concerned, there is evidence that diets that are high in roughage will result in higher rates of methane emission than diets high in starch, e.g. cereals. It has been argued (e.g. Shepherd et al., 2003) that this means emissions from organic animals will be higher than others, because of the emphasis in organic management on high-forage, low-cereal diets for ruminants. However, there is some discussion that diets high in tannins, which may be derived from clovers and trefoils for example, produce less methane than grass-only diets. Given the central role of clovers in organic grassland (because of the prohibition on synthetic nitrogen fertilizer), it may be that the methane emissions are actually lower from organic farms. In fact, clover may represent a triple gain for climate change: reducing methane emissions from animals, building soil organic matter and reducing reliance on synthetic nitrogen fertilizers.

Methane and CO_2 emissions are also relatively constant on a per animal basis so that, in principle, animals producing high yields will produce fewer emissions per litre than animals producing low yields. Again this would appear to count against organic farming. However, the average yield per cow on organic dairy farms is typically only about 10% lower than conventional, and there is no significant difference in the meat output per animal between organic and conventional systems, so this effect may be outweighed by other, farm or sector level, considerations such as stocking rates and reliance on bought in feeds from off the farm.

At the whole sector level, more account needs to be taken of balancing effect of reduced stocking rates in grassland areas compensating for increased livestock in organic arable and mixed farming systems.

Nitrous oxides

As indicated above, carbon containing gases such as CO_2 and methane are not the only greenhouse gases. Nitrogen containing gases, in particular ammonia and nitrous oxides, are also important. These may be generated from livestock manures (with implications for manure management practices) as well as soil biological processes involved in the nitrogen cycle, particular where there are large quantities of surplus nitrate and ammonium nitrogen in the soil available to be broken down by denitrifying microbes. However, a key source of nitrous oxides is the manufacture of fertilisers, as the data in Table 4 illustrate. Research has also demonstrated that grassland systems which rely on clover to fix nitrogen rather than high inputs of synthetic nitrogen fertilisers, typical of organic farming, have significantly lower levels of nitrogen losses to the environment in the form of nitrate leaching, ammonia volatilisation and denitrification as nitrogen or nitrous oxides.

Other sustainability issues

The research featured in this review covers several other sustainability issues where organic farming can make a contribution, but it is not possible to go into detail here.

Soil conservation

In addition to maintaining soil carbon levels, organic farming has been shown to reduce soil erosion, increase soil aggregate stability and stimulate soil biological activity.

Water resources

Organic management practices have been shown to help reduce nitrate leaching and phosphate run-off from soil erosion, leading to reduced eutrophication. They also reduce the potential for pesticide contamination, although some permitted products such as sheep dips may still represent a risk. Cropping practices such as mulching crop residues and maintaining ground cover in orchards and vineyards may also reduce irrigation requirements and help alleviate flood risks through improve soil water infiltration.

Biodiversity

Organic practices, and in particular the limitations on pesticide use, have been shown to have significant biodiversity benefits ranging from soil ecosystems, plants and insects to birds and mammals (Stolze et al., 2000; Shepherd et al., 2003; Hole et al., 2005).

Land and food security

Organic farming may provide these benefits, but it is argued by some that if this is at the expense of lower yields, more land will need to be brought into production, which will negate the benefits and put food security at risk. This is a complex question which involves consideration of role of meat in the diet, the benefits of integrating meat and crop production to achieve complementary use of resources, as well as organic farming helping increase self-reliance and productivity in resource poor countries. But perhaps this is insignificant compared with the changes in land use coming about through the increased production of biofuels.

Conclusions

Resource use self-sufficiency is a key organic principle, and nitrogen self-sufficiency is part of organic standards. Should energy use self-sufficiency and carbon-neutrality be given similar status? What is the role of renewable energies and organic biomass/fuels production in this context? What scope is there to improve everyday practices?

It is also important to consider the whole food system including processing, packaging, distribution, retailing and consumption (Foster et al., 2006). Much of the current debate is focused on local products, but local doesn't necessarily mean more sustainable if the production methods needed are inefficient. An even bigger challenge is the urbanisation of the population, which makes it difficult to localise production without fundamentally altering land use patterns.

Many of these issues will be addressed in today's conference and developed in a future version of this paper.

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