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The origin and hazard of inputs to crop protection in organic farming systems: are they sustainable?☆

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Abstract

Sustainability is defined as the ability of a system to 'continue'. In view of this definition, several aspects of the crop protection activity in organic farming are reviewed according to their ability to 'continue'. As no absolute measure of sustainability is available, this analysis takes the form of a comparison between organic and conventional crop protection methods. Two elements of crop protection are considered: one being the source of the inputs to crop protection and the other being the environmental hazard of the chemicals used in crop protection. In addition, the sustainability of some of the wider issues related to crop protection methods in organic farming are discussed. It is concluded that organic farming systems are not sustainable in the strictest sense. Considerable amounts of energy are input to organic farming systems, the majority of the compounds utilised in crop protection are derived from non-renewable sources and incur processing and transport costs prior to application. Further, these compounds are not without toxicological hazards to ecology or humans. Despite these problems, it is concluded that organic farming is probably more sustainable than conventional farming in a bio-physical sense. However, an assessment of the overall sustainability of farming systems may depend upon the valuation given by society to their inputs and outputs, and in this sense it is extremely difficult to assess which farming system is most sustainable.

Keywords: Organic farming; Pesticides; S ustainability

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1. Introduction

Much recent work has been concerned with discussing and analysing the sustainability of different farming systems (Brady, 1990; Edwards et al., 1990; Reintjes et al., 1992; Hansen and Jones, 1996). While in many ways this diverse array of work has been hampered by the lack of agreed definitions of "sustainability" and "sustainable farming systems", several common issues have emerged from these analyses which are deemed to be important in assessing a farming system's sustainability. These include soil fertility, energy efficiency, maintenance of yields, maintenance of genetic base of crops and animals, profitability, water quality, nature conservation and socio-economics. For the purpose of this analysis, the definition for 'sustainability' given by Hansen and Jones (1996) is adopted. This states "To sustain is literally 'to keep in existence: keep up; maintain or prolong' (Neufeldt, 1988). Sustainability can therefore be defined as the ability of a system to continue into the future." Here the emphasis is on "continue". This ability to continue is not related to any human-centred values or the perceived "quality" of the system, rather it is some fundamental characteristic of a system and its inputs and outputs. Thus theoretically, systems can be defined which have many desirable "quality" features, but because of the nature of their inputs, outputs and feedback mechanisms they may be unsustainable. Equally other systems may be sustainable, i.e. they have the ability to "continue", but they have no desirable "quality" features. In other words they may be systems which humans would consider to be "bad".

When undertaking a scientific analysis of the sustainability of any farming system, it is important that the analysis focuses on the characteristics of that system which are related to its ability to continue. Within agricultural systems, the ability to provide an economic return to the manager is one critical characteristic related to the system's ability to continue. Unprofitable agricultural systems will not continue. Related to this are issues concerned with maintaining output, such as soil fertility and reducing losses to weeds and pests. It is less easy to argue that a natural or diverse ecosystem is a critical input to a sustainable agricultural system. Some elements of ecosystems provide agriculturally valuable inputs, some do not. While ecologists frequently stress the inter-relationships between species, it is difficult to see how the existence of species such as the white-tailed eagle, the blue whale, swallow tail butterfly or the ghost orchid could contribute to a farming system's sustainability. The degree of redundancy in ecological communities is unknown, and remains a rich field of investigation for ecologists (Walker, 1992; Gitay et al., 1996). This is not to say that agriculture could continue in the absence of all non-farmed species. Rather, there is a suggestion that only a subset of all existing species are essential for food and fibre production.

Equally, there is some argument whether or not energy use should be an important component of sustainability analysis. Many analyses have considered energy use in agriculture systems (Leach and Slesser, 1973; Jones, 1989; Bonny, 1993; Panesar and Fluck, 1993; Ma and Edwards-Jones, 1997), and energy generation and use may be considered to be unsustainable (Keyfitz, 1993; Reid, 1995; Sathiendrakumar, 1996;

Ambroise, 1997). When viewed from the perspective of the definition of sustainability adopted here, this is certainly true of energy derived from non-renewable sources. The sources of fossil fuels are finite, and global ecosystems are unlikely to be able to continue unimpaired if persistently exposed to some of the pollutants associated with the use of fossil fuels. However, the use of energy from renewable sources would appear to be sustainable. So, while capturing energy from renewable sources and converting it into a useable form remains a technical constraint on many systems, in the long run, a technological optimist may suggest that as the amount of energy derived from renewable sources increases, so energy will not be a limiting factor in agriculture, and should not affect agricultural systems' ability to continue. However, should it prove impossible to capture energy from non-renewable sources then at some time in the future fossil fuel stocks would run out, and agricultural systems' ability to continue may be threatened (as would that of many other systems).

Energy from fossil fuel sources is not the only input derived from non-renewable sources used in agriculture, but to date the use of other non-renewables has received little attention in the literature (Leaver, 1994). This is unfortunate, as although stocks of many non-renewable resources are large and likely to be exploited for many years to come, there is no doubt that these stocks are finite, and should they run out then they may also impair agricultural systems' ability to continue. So ultimately, while no system which depends on non-renewable resources as inputs has the ability to continue indefinitely, those systems which use fewer non-renewable resources may be considered more "sustainable" then those which use greater amounts, but neither is truly sustainable over the long term.

The purpose of this paper is to compare the sustainability of so-called conventional systems with that of organic farming systems. Here organic farming is defined according to the criteria outlined by organic accreditation schemes (IFOAM, 1996). These regulations define a set of practices that effectively define organic agriculture. Amongst these regulations are some which prohibit the use of synthetic inputs of pesticides and fertilisers and stress the use of rotations and maintenance of soil fertility. Implementation of these regulations may result in real differences between organic and non-organic (i.e. conventional farms), and this is indeed what consumers of organic food are led to believe. However, some more academic definitions of organic agriculture move away from defining organic farming as a set of practices and define it more as a set of aspirations. For example, Henning et al. (1991, p. 877) suggest that:

> Organic agriculture is both a philosophy and a system of farming, grounded in values that reflect an awareness of ecological and social realities and the ability of the individual to take effective action. In practice, it is designed to work with natural processes to conserve resources, encourage self regulation through diversity, minimise waste and environmental impact, while preserving farm profitability. Such systems aim to produce food that is nutritious and uncontaminated with substances that could harm human health.

While Lampkin (1997, p. 322) suggests that:

> Organic farming can be defined as an approach to agriculture which aims for social, environmental and economic sustainability and animal welfare by: minimising use of external resources, maximising use of locally-derived renewable resources and agro-ecosystem management and using the market to compensate for internalising external costs. As such, organic farming shares the fundamental objectives of agricultural sustainability and deserves to be assessed with LISA/ICM[[1]; footnote added] as a mainstream part of sustainable agriculture.

Thus both Henning et al. (1991) and Lampkin (1997) suggest that almost by definition, organic agriculture is good for the environment and society, and similarly almost by definition it is sustainable. However, given recent political movements aimed at encouraging increased amounts of organic agriculture across Europe (Dabbert, 1997), then rather than simply accept aspirational statements about the good intents of organic farming, it seems necessary to test for any tangible differences between organic and conventional agriculture. Biologists have attempted to do this by testing for differences in species richness and abundance in organic and conventional farms (Hesler et al., 1993; Carcamo et al., 1995; Feber et al., 1997; Fuller, 1997; Lokemoen and Beiser, 1997; Moreby and Sotherton, 1997) and economic analyses have compared the relative profitability of the two systems (Dobbs and Smolik, 1996; Hanson et al., 1997; Hindhede et al., 1997; Klepper et al., 1977; Eder, 1998). This paper aims to continue with such explorations of differences between organic and conventional farming systems, as regards the relative sustainability of the crop protection activity in conventional and organic farming.[2]

The purpose here is to explore whether or not the two farming systems are fundamentally different in terms of the sustainability of their crop protection activities, and, if both are unsustainable, to explore the reasons for their non-sustainability. While we recognise that different farming systems have different environmental impacts, the focus of this analysis is not on degrees of impact, rather it seeks to ask whether there are any real fundamental differences in the sustainability of organic and conventional farming, or in the sources of their unsustainability. As such, it is more a philosophical discussion rather than an empirical analysis.

Specifically, this paper seeks to address two questions related to the sustainability of crop protection practices in organic and conventional farming. Firstly, it examines the source of the inputs to crop protection in organic and conventional farming. The assumption being that lower use of non-renewable resources is more sustainable than greater use. Secondly, the paper considers the hazard to the environment posed by substances used for crop protection in organic and conventional farms. Finally, some of the wider issues related to the pest management in organic farming are considered.

[1] Low Input Sustainable Agriculture/Integrated Crop Management.

[2] We acknowledge that in many ways breaking down the functions of an organic farm system, and analysing only one component, is counter to the commonly held philosophy that organic farming treats the system as a whole. However, a consideration of the entire system would be beyond the scope of one article.

2. Methods

2.1. Source of inputs to crop protection on organic farms

The study sought to review data on the source of inputs to crop protection in organic and conventional agriculture and to consider the environmental hazard arising from the application of crop protection chemicals in the field. Given the integrated nature of the organic farming ethos (IFOAM, 1996) it proved difficult to separate out the inputs to cropping systems in terms of crop protection and plant nutrition; a healthy plant is believed to be able to better resist pest attacks. For this reason, both crop protection and plant nutrient inputs were considered simultaneously. Information on all permissible inputs to organic farms in the UK was obtained from the Soil Association (1996). Data on the use, source and processing associated with each of these inputs was collated from the literature.

2.2. Estimating the environmental hazard of pesticides approved for use on organic farms

The environmental hazard of the inputs to crop protection in organic farming was estimated using a method for representing the environmental impact of pesticides developed by Kovach et al. (1992); the so-called environmental impact quotient (EIQ) method.[3] This framework enables data on the various environmental effects of pesticides to be reduced to a single value called the EIQ. This method is not unique in seeking to represent pesticide hazard in this way, and several other indices exist (Higley and Wintersteen, 1992; Reus and Pak, 1993; Levitan et al., 1995; Edwards-Jones et al., 1998; Reus et al., 1999). However the EIQ method possesses features which predispose it for use in policy and environmental decision making (Quin and Edwards-Jones, 1997; Edwards-Jones et al., 1998), and a recent proposal suggested that a modified form of the index could be used to set a pesticide tax in the UK (DETR, 1999).

2.2.1. The EIQ model

The EIQ model was specifically developed to allow farmers wishing to practice Integrated Pest Management to incorporate environmental considerations into their decision-making process. The EIQ model provides information on the potential toxicological hazard of individual pesticides, thereby enabling farmers (or other decision makers) to select between pesticides according to their hazard rating. This is achieved by reducing data for 11 toxicological and physio-chemical variables to a single figure: the EIQ. The relative importance of each variable in the overall hazard assessment is determined by a weighting factor; the higher the weight the more

[3] Strictly speaking the EIQ estimates the hazard associated with different active ingredients in proprietary products. The word 'pesticide' is used throughout the paper to ease comprehension, except where there is a specific need to differentiate between the active ingredient and the proprietary product.

important that variable. The weights allocated in the original EIQ model were restricted to 1, 3 and 5 corresponding to low, medium and high, respectively.

The EIQ model examines the hazard to farmworkers, consumers and ecological factors separately. Particular data are manipulated within each of these three sub-categories in order to represent the hazard of a pesticide to that category of potential impact. The equations for the three sub-categories are:

$$\text{EIQfarmworker} = C \times (\text{DT} \times 5) + (\text{DT} \times P)$$

$$\text{EIQconsumer} = \text{C} \times ((S + P)/2) \times \text{SY} + L$$

$$\text{EIQecological} = (F \times R) + (D \times ((S + P)/2) \times 3 + (Z \times P \times 3) + (B \times P \times 5)$$

where DT, dermal toxicity; *D*, bird toxicity; *C*, chronic toxicity; *S*, soil half life; SY, systemicity; *Z*, bee toxicity; *F*, fish toxicity; *B*, beneficial arthropod toxicity; *L*, leaching potential; *P*, plant surface half life; and *R*, surface loss potential.

The final EIQ is the average of the three sub-categories and is derived as:

$$\text{EIQ} = \{[C(\text{DT} \times 5) + (\text{DT} \times P)] + \; C \times (S + P)/2 \times \text{SY}) + (L)] + [(F \times R) + (D \times (S + P)/2 \times 3) + (Z \times P \times 3) + (B \times P \times 5)]\}/3$$

An amendment to the basic EIQ, the Field Use Rating (FUR), allows data on individual pesticides to be expressed in terms of pest management strategies at the farm level. The (FUR) is calculated as:

$$\text{FUR} = \text{EIQ} \times \%\ \text{a.i.} \times R$$

where EIQ, the environmental impact quotient for a given active ingredient; % a.i., the percentage active ingredient in a given proprietary pesticide product; and *R*, total amount of the pesticide used (usually expressed as kilogramme per hectare).

3. Results

3.1. Source of inputs to crop protection on organic farms

3.1.1. Pesticide use on organic farms

Certain mineral and chemical compounds are approved for use by organic standards committees on the basis that they are not synthetic (Table 1). Of the 10 insecticides and fungicides approved for use in the UK under the Soil Association's Symbol Scheme, only three are obtained from wholly renewable sources; these are *Bacillus thuringiensis*, derris and pyrethrum (Table 2). The former is a bacterial

Table 1
The source of materials used in Soil Association approved insecticide and fungicides, and their uses

Bacillus thuringiensis is a bacterial insecticide used for controlling caterpillars. It is non-toxic to other organisms. It is produced by fermentation under well-controlled conditions. Its specificity to pests, combined with a natural safety to man and pest predator species make it suitable for use in pest management (Tomlin, 1994)
Derris is a natural contact insecticide formulated from plant extracts, which is most effectively applied as a medium volume spray. Liquid derris typically contains 5% of the active ingredient which is rotenone. Rotenone has a short half-life and therefore degrades rapidly. Rotenone is derived from the root of the plant *Derris eliptica*, which is imported whole, largely from the USA, and is then processed in the UK (Williams, personal communication). It is a broad spectrum insecticide which is toxic to bees, fish and predatory insects and, as such, is used on a restricted basis only
Soft soaps are soap concentrate insecticides which may also be called potassium soaps or fatty acids. They are effective against mites, thrips and aphids and are applied as sprays
Pyrethrum is a natural contact insecticide derived from the leaves of the plant *Chrysanthemum cineriafolium*. A low toxicity to mammals, short persistence in the environment, yet rapid action on insects make it an ideal pesticide. The plant extract can be refined using methanol or carbondioxide. The dried flower heads used in processing are principally exported from Kenya, Tanzania and Tasmania where the plants are grown as a crop (Tomlin, 1994). Pyrethrum is toxic to fish and, as such, its use is restricted adjacent to water bodies where the risk of contamination is high
Metaldehyde is a molluscicide bait applied in pellet form, solely used for the control of slugs and snails in agriculture and horticulture. It is non-phytotoxic only when used as recommended, i.e. when contained within traps so as not to come into contact with plant foliage or the soil. Due to it high level of toxicity to mammals it must contain a repellent to higher animal species (Soil Association, 1996). It has a high chronic toxicity and is a highly processed substance
Bordeaux mixture is an inorganic foliar fungicide that is applied as a high volume spray at a certain stage of the growing cycle, when its phytotoxicity is low. It is most commonly applied to potatoes and soft fruit. The active ingredient is copper, with a typical Bordeaux mix containing approximately 30 g per litre (Williams, personal communication). There is concern over the toxicity of copper and the persistence of residues in the environment and, as such, it is not advocated for routine use
Sulphur is a broad spectrum inorganic contact fungicide that may also be used as a foliar feed. It may be applied in the form of a soluble spray or as dust. Sulphur is most commonly applied in a near pure form, a typical mix constituting of 99.8% sulphur and 0.2% ash. Sulphur degrades rapidly and is non-toxic to bees and fish. There is no commercial production of sulphur in the UK, hence it is imported from the continent
Copper ammonium carbonate is a protectant copper fungicide applied at rates of approximately 25 g per litre. Its properties are assumed to be comparable to those of copper oxychloride (see below)
Copper oxychloride is a foliar copper fungicide and bactericide with a protective action. It was first used in the early 1900s. It is non-phytotoxic when used at recommended rates, except to carrots and potatoes under certain conditions. There is some concern over the toxicity of copper and the accumulation of residues in soil and biota, and as such it is not recommended for routine use. Copper oxychloride is toxic to fish
Copper sulphate is a copper-based aquatic algicide and contact fungicide. It is commonly combined with lime to form Bordeaux mixture. In soil copper sulphate is partly washed down to soil levels where it is partially bound (Tomlin, 1994). The concern over the persistence of copper in the soil means it is not recommended for routine use. Copper sulphate is toxic to fish

Table 2
The source of the active ingredients in insecticides and fungicides approved for use in the UK by the Soil Association, the degree of processing required prior to their application and details of method of application and pest/disease which they control[a]

Product	Source		Degree of processing	Form of application	Pest controlled	Country of origin
	Renewable	Non-renewable				
Insecticides						
Bacillus thuringiensis	✓		Medium	Spray	Caterpillars	USA
Derris/rotenone	✓		Low	Spray	Aphids	USA
Soft soaps/oils	✓	✓	Medium	Spray	Aphids, thrips	Various
Pyrethrum	✓		Low	Spray	Caterpillars	Kenya, Tanzania, Tasmania
Metaldehyde[a]*		✓	High	Pellets	Slugs and snails	Various
Fungicides						
Bordeaux mixture		✓	High	Spray	Blight, mildew,	Various
Sulphur		✓	Low	Dust	Mites, mildew, blight	Switzerland, France
Copper ammonium carbonate		✓	High	Spray	Blight, mildew	Various
Copper oxychloride		✓	High	Spray/ powder	Canker, mildew, blight	Various
Copper sulphate		✓	High	Spray	Blight, mildew	Various

[a] Preparations contain a repellent to higher animal species and must be applied within traps to prevent contact with the soil.

spray, the active ingredient of which can be cultured under controlled conditions. The active ingredients of the latter two are plant derivatives, from non-threatened plant species cultivated under crop conditions. Of the other seven products, four utilise the toxic effects of copper, and only one could be converted to use a renewable active ingredient, this being soft soap. Soft soaps often contain potassium which can readily be supplemented with oils extracted from plants.

3.1.2. Nutrient supplement products used on organic farms

Supplementary nutrients in the form of mineral and organic fertilisers may form an important part of organic crop protection programmes. These additional nutrients promote mechanical resistance in the plant cells and reduce the susceptibility of plants to attack. Silica is particularly valuable for minimising the effects of sucking insects or fungal mycelia by strengthening the walls of plant cells. Rock dusts containing silica are a typical source of this mineral, as well as acting as anti-feedants (Lampkin, 1990).

Table 3 lists a selection of nutrient supplements approved for use under the Soil Association's Organic Symbol Scheme. Over half of the substances listed are from

Table 3
The source of a selection of supplementary nutrients approved for use in the UK by the Soil Association, and a qualitative measure of the degree of processing they require prior to application

Product	Source		Degree of processing	Source
	Renewable	Non-renewable		
Nitrogen fertilisers				
Dried blood	✓		Low	UK
Hoof and horn meal	✓		Medium	UK
Phosphate fertilisers				
Rock phosphate		✓	Medium	Tunisia
Calcined aluminium phosphate		✓	Medium	Tunisia
Basic slag		✓	Low	UK
Potassium fertilisers				
Rock potash		✓	Medium	UK
Sulphate of potash		✓	Medium	UK
Minerals and trace elements				
Ground chalk and limestone		✓	Medium	UK
Feldspar		✓	Medium	UK
Gypsum		✓	Medium	UK
Steelworks slag		✓	Medium	UK
Compound fertilisers				
Fishmeal	✓		Medium	UK
Farmyard manure	✓		Low	Local
Liquid seaweed	✓		Medium	UK
Biodynamic preparations	✓		Low/medium	UK

non-renewable sources, all of which are mined or quarried. Both of these processes have major environmental impacts associated with them, which, when coupled with the required processing and transport associated with a number of these mineral products, make it evident that their use is not sustainable. Further, the use of these non-renewable resources may have environmental or ethical implications. For example, the 22 million tonnes of marine fish caught annually for industrial reduction to fishmeal, oil, etc., are exclusively caught by large-scale fisheries, often fishing already depleted stocks, which have a by-catch (non-target fish killed but not landed) of around 25% (Tolba and El-Kholy, 1992; Laura Cooper, personal communication).

3.2. The environmental hazard of pesticides approved for use on organic farms

The EIQ values of the pesticides approved by the Soil Association for use on organic farms in the UK ranged from 13.5 to 67.7, with an average value of 31.2 (Table 4). Rotenone scored slightly above average overall, with a particularly high score for the farmworker component. Metaldehyde scored low overall despite having a very high ecological component score. This is partly due to its very restricted

Table 4
An assessment of the environmental hazards of insecticides and fungicides approved for use in the UK by the Soil Association according to their environmental impact quotient (EIQ) (after Kovach et al., 1992)

Product	Effects on each variable								Effect on sub-categories			EIQ
	Applicator	Picker	Consumer	Groundwater	Aquatic	Bird	Bee	Beneficial	Farmworker	Consumer	Ecology	
Insecticides												
Bacillus thuringiensis	10.0	2.0	4.0	2.0	3.2	6	3	10.3	12.0	6.0	22.5	13.5
Derris/ rotenone	45.0	9.0	3.0	1.0	16.0	3	3	19.0	54.0	4.0	41.0	33.0
Soft soap	9.5	1.9	3.1	2.0	12.5	16	3	10.0	11.4	5.1	41.8	19.5
Pyrethrum	5.0	1.0	1.0	2.0	16.0	9	3	17.0	6.0	3.0	45.0	18.0
Metaldehyde[a]	5.0	3.0	6.0	5.0	1.0	6	9	52.5	8.0	11.0	68.5	29.2
Fungicides												
Bordeaux mix	67.5	40.5	18.0	1.0	25.0	12	9	30.0	108.0	19.0	76.0	67.7
Sulphur	5.0	5.0	5.0	1.0	3.6	15	15	87.0	10.0	6.0	120.0	45.5
Copper oxychloride[b]	7.5	4.7	4.1	1.0	10.8	24	9	38.3	12.2	5.1	82.7	33.3
Copper sulphate	67.5	13.5	13.5	1.0	25.0	9	3	10.9	81.0	14.5	47.9	47.8

[a] Used figures for metalaxyl.
[b] Used figures for copper hydroxide. No information was available for copper ammonium carbonate.

application in a low risk manner, i.e. in a contained environment in pellet form. Sulphur has one of the highest ecological component scores of any pesticide (organic or synthetic). The copper-based fungicide, copper sulphate, has a high farmworker component score due to its high levels of dermal and chronic toxicity. The average EIQ value for the 84 conventional insecticides and fungicides analysed by Kovach et al. (1992) was 41.5, ranging from 12.8 to 121.9. Table 5 shows a complete assessment for a sample of 10 pesticides which might typically be used in a conventional farming system.

In order to compare the potential environmental hazard of pesticides, the dosage, the percentage of active ingredient and the frequency of the application need to be considered. Within the EIQ framework this is achieved by calculating the FUR. This EIQ FUR can be used to indicate the least damaging pesticide suitable for controlling a particular pest problem. An insecticide with a low EIQ that requires a greater number of applications may be shown to carry a greater environmental hazard than a low dosage chemical with a high EIQ. Indeed Kovach et al. (1992) found that for apple production in the USA, an organic pest management strategy had twice the total environmental impact score of traditional pest management strategies. The same organic management strategy had over 10 times the total environmental impact score than the least damaging integrated pest management strategy. This was due the high number of applications required for sulphur ($\times 7$) and rotenone ($\times 6$) to be effective in the organic system.

3.3. Some wider issues related to pest management in organic agriculture

A negative impact arising from the increased use of crop rotations as a replacement for synthetic pesticides is the potential disruption to fauna and flora communities due to continual changes in the crops grown (Arden-Clarke, 1988). Such disruption can have a negative impact on both the diversity and abundance of species. Regular cultivation of leys can have a direct negative impact on beneficial as well as pest species, through burying or desiccation. A number of authors, including Pimentel et al. (1983) and Stinner et al. (1986), cite the disruption of soil fauna communities as one potentially negative impact of organic pest control strategies. Evidence of low floral diversity in clover-grass leys and the slow build up of insect populations and insect species diversity within those leys, support this suggestion (Purvis and Curry, 1980). A constantly changing environment is likely to favour certain species within the crop environment itself. However, it seems likely that other benefits afforded by reduced chemical use, e.g. the retention of field margin flora and increased organic content of the soil, will have beneficial implications for biodiversity that may outweigh these negative effects of crop rotations. In addition, the increased application of supplementary nutrients in organic systems may have a negative effect, particularly where high levels of manure are applied on grasslands utilised for hay and silage (Redman, 1992). Excessive applications of manure can be particularly damaging to earthworm populations.

Through the use of crop rotations, organic farming encourages diversity at the landscape scale. Such retention of a diversity of habitats confers obvious benefits on

Table 5
An assessment of the environmental hazard of insecticides and fungicides typically used in conventional farming systems according to their environmental impact quotient (EIQ) (after Kovach et al., 1992)

Product	Effects on each variable								Effect on sub-categories			EIQ
	Applicator	Picker	Consumer	Groundwater	Aquatic	Bird	Bee	Beneficial	Farmworker	Consumer	Ecology	
Insecticides												
Carbofuran	60.0	12.0	24.0	5.0	5.0	30	15	19.4	72.0	29.0	69.4	56.8
Diflubenzuron	7.5	7.5	4.5	1.0	5.0	9	15	69.0	15.0	5.5	98.0	39.5
Ethoprop	41.7	15.8	4.1	5.0	9.0	22.1	17	19.0	57.5	9.1	67.2	44.6
Methoxychlor	12.5	12.5	12.5	1.0	16.0	15	15	89.5	25.0	13.5	135.5	58.0
Propoxur	45.0	27.0	12.0	1.0	16.0	60	45	55.8	72.0	13.0	176.8	87.3
Fungicides												
Chlorothalonil	12.5	12.5	10.0	1.0	25.0	12	15	50.0	25.0	11.0	102.0	46.0
Dichloran	15.0	9.3	6.2	1.0	25.0	9	9	32.9	24.3	7.2	76.4	35.9
Fentin-hydroxide	15.0	9.0	4.0	1.0	18.0	12	9	30.0	24.0	5.0	69.0	32.7
Mancozeb	20.0	20.0	16.0	1.0	25.0	12	15	78.0	40.0	17.0	130.0	62.3
PCNB	12.5	2.5	7.5	1.0	15.0	9	3	15.0	15.0	8.5	42.0	21.8

local wildlife populations. Organic farming may, therefore, help maintain traditional agricultural landscapes by promoting a smaller average field size and retaining boundary features. Such landscapes have great aesthetic appeal and are considered to enhance the countryside. Improving the scenic or landscape appeal of rural areas improves their value for both formal and informal recreation and has traditionally formed part of the intrinsic appeal of the countryside, the economic implications of which may be considerable.

4. Discussion

No fungicide currently approved for use in the UK by the Soil Association is derived from a renewable source. Four of the five insecticides are derived from renewable sources, but all require some processing prior to application. This processing and subsequent transport utilises energy, and may be dependent on machines made from non-renewable resources. This situation compares reasonably favourably with the conventional situation where most, if not all pesticides and herbicides are derived from fossil fuels, and Pimentel and Hall (1984) estimated that in the early 1980s, average energy input for the production of herbicides in the US was approximately 424.8 MJ/kg, 369.4 MJ/kg for insecticides, and 275.9 MJ/kg for fungicides.

Generally, pesticides and fungicides permitted for use in organic farms are less hazardous than those used in conventional systems, but there are some clear exceptions to this rule. However, some evidence suggests that when toxicity and volume are considered in an overall pest management strategy, organic practices may have greater environmental hazard than conventional ones (Kovach et al., 1992). For these reasons, we can state that the crop protection activity of organic farming, and hence organic farming itself, is not absolutely sustainable. That is, it could not continue indefinitely as the inputs to the system are derived from non-renewable sources, and the use of crop protection chemicals in organic systems is not without environmental hazard. We can, therefore, conclude that neither conventional nor organic systems are absolutely sustainable, and the classes of problem associated with the non-sustainability of conventional farming systems are common to organic farming systems too. Fundamentally, both systems are non-sustainable because they require inputs of non-renewable resources, and both systems impact on the natural environmental in one way or another. In this situation, it could be argued that the system which uses less non-renewable resources, and/or has least environmental impact, will continue longer than the other. In an absolute sense this is true, and in an experiment where two similar-sized farms were started on the same day, each with access to a similar, finite, amount of non-renewable resources, then other things being equal, the system which used less non-renewables per unit time would be expected to continue for more time periods than the system which used more resources per unit time. Thus, according to Hansen and Jones' (1996) definition one system would be more sustainable than another.

Such analyses only consider the inputs to the system. A more realistic analysis may require a consideration of both the inputs and the outputs associated with a farming system. For example, if consumers were not prepared to buy the output of one of the systems, then its ability to continue would be severely compromised, regardless of the use it made of non-renewable resources. However, not all outputs need be in terms of marketable food or fibre; environmental and social goods can also be deemed as outputs of farming systems.

Given this range of outputs, and inputs, there may be a problem in defining the inputs and outputs in units which permit an easy comparison. In an analogous situation, Pearce and Atkinson (1993) suggest that inputs and outputs could be stated in monetary terms. The acceptance of this proposition inevitably means that the 'quality' aspects of a system will be combined with its 'absolute' characteristics, as the conversion of any good to monetary terms requires some valuation of that good, and value is inherently anthropocentric, and will vary with situation. If such a monetary valuation was undertaken, one test of sustainability may be given by the inequality:

$$S \text{ if } \mathrm{Vo} > \mathrm{Vi}$$

where S, sustainable; Vo, value of the outputs from a system over the long term; and Vi, value of the inputs to a system over the long term.

If it were assumed that the scarcity of non-renewable resources would be reflected in their price, which would influence Vi over time, then a feedback mechanism between resource availability and sustainability could be achieved. While this may provide a satisfactory treatise of inputs to the farm system, it is apparent that the major difficulty in this approach concerns estimating Vo, and its fluctuation over time. For example, consumers may value several, potentially conflicting, characteristics of a farming system, e.g. the provision of sufficient amounts of food, the provision of cheap food, the provision of high quality food, and the provision of a constant supply of food. Further, there may be some social value attached to the provision of employment on farms and in the upstream and downstream industries, and to the provision of ecological goods. Finally, at a global level, there may be value associated with the ability of farming systems to provide food for a rapidly growing world population. The values attached to these outputs for conventional and organic farming may differ substantially. For example, while conventional agriculture can supply a constant supply of relatively cheap food, organic agriculture probably provides greater on-farm employment and many ecological goods, but it is currently not able to provide a high and constant output of food. While such qualitative comparisons are relatively easy to undertake, there are immense difficulties inherent in quantifying their monetary values for any farming system, and this they may prevent any such analysis from being undertaken in the short term.

In conclusion, this paper has shown that the crop protection activities associated with organic farming are not sustainable in an absolute sense, and organic farms are subject to the same class of non-sustainable characteristics as conventional farms. It could be argued that just because certain products are permitted for use on organic farms under the Soil Association regulations, this does not mean that all organic farmers use them, and hence many of the arguments presented here are irrelevant. This is true, but it could equally be argued that there is no certainty that conventional farmers will use synthetic pesticides. So whilst we acknowledge this point we do not feel it helps answer the questions addressed here, which were concerned with the ultimate causes of unsustainability rather than an empirical measurement of sustainability. If such a measurement of sustainability was undertaken, then in a biophysical sense organic farms may be able to 'continue' for longer than conventional farms, but it is apparent that this ability alone does not mean they are either more sustainable, or more desirable than conventional systems. Rather, such statements can only be made after considering the value placed by society on both the inputs and outputs associated with the two farming systems.

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