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### What is 'organic' farming?

**The principle** There is no single definition for 'organic' farming as the term applies to a movement rather than to a single policy. However, a general feeling for what is 'organic' and what is not can be obtained from the aims of the most prominent associ-

ations or organisations within the organic movement. Within the UK, these include the Soil Association. The Soil Association exists "to research, develop and promote sustainable relationships between the soil, plants, animals, people and the biosphere, in order to produce healthy food and other products while protecting and enhancing the environment".

The unifying principle behind most advocates of organic farming and gardening is the belief that the health of the soil is paramount for life and is the only long-term, sustainable way of cultivating land and creating a secure future for the world.

It would seem to be unreasonable to oppose these broad objectives and so the Agriculture Departments in the UK have accepted that "well practised organic farming is among the options available for environmentally friendly and sustainable production"<sup>1</sup>, and that "Organic farming brings benefits to the environment and the consumer through reductions in the use of chemicals and production of food in a healthy natural environment"<sup>2</sup>. The government's Organic Farming Scheme is designed to help encourage an expansion of organic production by providing financial help to farmers and growers when converting to organic methods, a process that lasts for two or more years. Thereafter, produce can be marketed as 'organic'.

Later in this article we will consider whether all of the subsequent implementations of these principles are necessarily so environmentally friendly.

**The justification** The Soil Association was founded by people who perceived that intensive agricultural systems led to loss of soil through erosion and depletion, decreased the nutritional quality of food, exploited animals in intensive units, and had deleterious effects on the countryside and wildlife. The Soil Association assembled a view of how the best traditions in land and crop management could be combined, and the system of husbandry that they promulgated has since become known as organic

"Demand for organic produce is strong and still growing. We are determined that consumers should be able to buy organic produce if they want to. We must remember that conventional systems also produce good quality food that is safe to eat in the quantities consumers demand"

Mr N Brown, Agriculture Minister, 12 April, 1999 launching a new Organic Farming Scheme. farming. The standards that they compiled, together with additions over 25 years, are now used to define the organic system. About 80% of UK organic food is certified by the Soil Association.

Currently, the demand for organic food exceeds the supply from UK sources so that

about 70% of organic food is imported from continental European and US sources and organic produce currently attracts premium prices. Organic land in the UK is still less than 0.5% of the agricultural area compared with about 4% in Germany, 5% in Denmark and 8% in Austria, for example.

We have to be clear about which arguments support organic farming on scientific and environmental grounds and which support it on economic grounds. It would seem to be a basic tenet of a free market that nothing that is in adequate supply will attract a premium in price. Note that with those levels of production on the continent, producers there are willing and able to export to the UK at British prices. This could suggest that a similar level of organic farming in the UK would satisfy the market and remove the need for premium prices. Proponents of organic farming should consider, therefore, the possible future economics of organic production if the supply were to increase to meet demand and prices fell to world levels for each commodity. If there are economic benefits then the system will need no support, science or no; and there is growing evidence from within the movement that farmers can reduce external inputs significantly without losing on gross margins, as variable costs are reduced as well as yields. Generally the loss in yield per hectare is 5 - 10 per cent for crops (Table 1) and 10 - 20 per cent for livestock<sup>3</sup>. There are more recent reports of profitability. For example, the report on MAFF project OF0112<sup>4</sup> stated "Gross margins

Enterprise - description	Crop yields	Pesticide use	Fertilizer use	Gross margins
Integrated crop rotations of cereals and legumes, W England	89 - 92%	10 - 81%	69%	103 - 116%
Environment- ally benign sugar beet system, E England	78%	nd	nd	102%
Alternative rotation and low input system, W England	S beans 88% Oats 105%	0 - 50% 50%	nd 50%	96% 112%
Standard rotation, low input approach, S England	99.6%	Insecticide 0% Fungicide 50%	nd nd	101% 101%
Reduced fungicide on spring barley, Scotland	102%	12 - 25%	nd	126 - 152%
Supervised low input pesticides on wheat and rape, E. England	Wheat 88% OSR 105%	15 - 54% 0 - 96%	nd nd	105% 139%
Integrated farm, the Netherlands	94%	26 - 50%	26%	120%
Biodynamic farms, Baden Wurtemburg, Germany	75 - 91%	zero	zero	80 - 101%
8 biodynamic farms, Switzerland	95 - 100%	zero	zero	100%
Individual organic and 'semi organic' farms, data for wheat, UK	53 - 114%	zero	zero	57 - 138%
58 organic farms, 1986 - 91, Switzerland	73%	P 6%	22%	83%
200 whole mixed farms, 1986 - 91, Germany	Wheat 66% Rye 67% Potato 61%	P 6%	3%	105%
Lautenbach integrated and conventional farms, Germany	99 - 105%	zero	75%	104 - 109%

From Table 7.2 p209. In, *Regenerating Agriculture* by J.N Pretty, Earthscan, London, 1995.

**Table 1** Economic indicators for performance of cropcomponents and complete farms of 'sustainable'agriculture in UK and continental Europe as proportion(%) of conventional.

following conversion have been consistently greater than for conventional crops'. Again, SAC in their evidence to the House of Lords<sup>5</sup> stated 'Using SAC's own financial modelling packages, .. even for these allarable farms, a change to organic production leads to a significant improvement in profitability'.

On the other hand, if the environmental concerns are uppermost then economics are secondary and organic farming may need central support but, in that case, the environmental benefits must be testable and proven.

Encouragement of organic farming EU Member States have promoted organic farming in a variety of ways, principally by subsidies for organic farmers via schemes under Regulation 2078/92. The details of schemes vary widely, most being open to all organic farmers but some only to those converting to organic production. Details of the provisions in the UK can be found at the MAFF and SERAD web sites. Information on the variety of schemes applied within the EU is outlined in a House of Lords Report<sup>6</sup>. Support for converting and continuing organic production from the Community and Member States is estimated to have amounted to over 260 million ecu in 1997. Organic farmers are of course also eligible for support under the various CAP regimes in the same way as other farmers. For British farmers, aid is available through the Organic Farming Scheme or its equivalents in Scotland, Wales, and Northern Ireland. For land eligible for the Arable Area Payments Scheme (AAPS), payments will total £450 plus £600 per farm over the first 3 years<sup>6</sup>.

Organic farming is also supported in a variety of other ways. In England, for example, MAFF fund an Organic Conversion Information Service (OCIS), which is run by the Elm Farm Research Centre. Similar schemes exist in Scotland, Wales and Northern Ireland<sup>6</sup>. Equivalent advice for farmers wishing to use lower inputs in conventional agriculture is neither readily available nor free.

The Government also provides research and development funding for organic farming: the MAFF organic research and development budget for 1999-2000 is  $\pounds 2.1$  million. MAFF marketing grants totalling  $\pounds 1.3$ million have also been given out to organic groups<sup>6</sup>.

**The regulation** By April 1999, 60,000 ha of agricultural land in the UK had gained full 'organic' status and another 180,000 ha was undergoing the 2-year conversion together making 1.3% of the total agricultural area. Forty-four percent of that land is classed as unimproved grazing, mainly used for extensive rearing of livestock.

ORGANIC STANDARDS Minimum requirements are set by the EU, the United Kingdom Register of Organic Food Standards (UKROFS, the government control body responsible for implementing the EU regulations in the UK) and the International Federation of Organic Agricultural Movements (IFOAM) and the standards are reviewed regularly.

The standards cover all aspects of organic production during the two-or-more-year conversion period and thereafter, from crop rotations, through management practices for control of weeds, pests and diseases and maintenance of soil fertility, to livestock management<sup>7</sup>. Many of the recommended practices are clearly beneficial. For example, soil management must ensure: a regular input of organic residues in the form of manures and plant remains to maintain the level of humus, biological activity and plant nutrients; a level of microbial activity sufficient to initiate the decay of organic materials ... into simple nutrient salts capable of being absorbed by plant roots; and conditions conducive to the continual activity of earthworms and the stabilisation of soil structure. The value of these practices would not be contested; but note that "simple nutrient salts" principally means ammonium and nitrate ions. However, the features that really characterise the organic system are the avoidance of soluble mineral salts as applied fertilizers and the prohibition of agro-chemical biocides. In effect, they forbid a range of practices that are otherwise widely adopted throughout the developed world. The 'soluble mineral salts' that are forbidden are generally the identical 'simple nutrient salts' that are recommended in the organic system when released in uncontrolled quantities by the mineralization of organic matter.

There is one other characteristic that has been included more recently, and that is the attitude towards genetically modified organisms (GMO) and that will be considered later.

### The claims and independent assessments

There can be little argument that the adoption of organic farming practices will lead to a number of benefits. So, a project funded by MAFF<sup>4</sup> found that numbers of earthworms increased markedly, and stability of soil aggregates increased giving a more freely draining soil with better structure that needed less

"...no other farming systems show such consistent benefits for wildlife.

... crops are habitat just as surely as heather moorland, ... "

MSP Sarah Boyack, Labour Minister for Transport and Environment 2 October 1999.

work to cultivate it. However, these benefits were associated with an altered and better crop rotation. Almost certainly, it was that rotation rather than the low inputs *per se* which led to the improvements. Data in Table 2, from an independent study that did not involve low inputs, confirm this. Equally, it is clear that the elimination of agro-chemicals in arable areas will lead to increased populations of insects and other biota. What is less clear is whether the changes will be beneficial to people in any real way.

Treatment** :	1	2	3	4	
Soil Organic Matter	2.32	2.16	2.08	2.01	
Relative %	100	93	90	87	
Instability	1.23	1.25	1.33	1.39	
Relative %	100	102	108	113	
Crust formation %	83.0	88.4	90.6	91.9	
Relative %	100	107	109	111	
** Initial soil organic matter = 2.08%					

Treatments

 $1=40\ t\ ha^{-1}$  farmyard manure every 3 years + green manure every 3 years

2 = Input of all crop residues + green manure every 3 years

3 = Green manure every 3 years

 $\mathbf{4}=\mathbf{B}\mathbf{lank},$  no supplementary input of organic material except roots and stubble

**Table 2**Influence of long-term inputs (10 years) ofdifferent organic materials on soil organic matter,aggregate instability, and crust formation in silt loamsoils $^8$ .

**Pesticides** SCARAB (MAFF Project PS0401), which was primarily driven by the need to make in-depth observations on the ecological effects of pesticides, found few long-term direct effects of pesticides on non-target insect or spider populations even when they were used at full, manufacturers' recommended rates. However, there were some non-target insects (including ground beetles) and spiders that suffered significant short-term reductions following individual applications of certain pesticides. There was no apparent evidence of long-term trends within any individual species of earthworm. These findings would seem to suggest that the ecological benefits of eliminating pesticides may be more apparent than real. On the other hand, the TALISMAN project (MAFF Project

PS0402) showed that reduced (but positive) use of insecticides improved gross margins on average by 1%. In over 90% of cases there were no significant economic losses, even when certain insecticides were omitted altogether, which suggests that the normal usage in conventional agriculture is higher than it needs to be. It is almost certain that a more flexible approach to reduced use of pesticides could achieve the treble aims of lowering chemical inputs, not damaging the environment, and maintaining profitability.

**Quality of food** A survey by MORI in June 1999 showed that one third of the public had bought organic food in the previous three months; over half of them because they believed it to be safe and healthy. This attitude is, presumably, based on the perception that hazards in foods derive from agrochemical additives, whereas microbes, not chemicals, are the major source of foodborne illnesses<sup>9</sup>

There are many claims made of organic food, most unsubstantiated and many unwarranted. For example, common claims include 10: "Organic food is better for you." Has that been proven? And, if so, in what way? We have not found consistent and valid reports of differences in the mineral contents of organic and conventional foods. An early report<sup>11</sup> of differences in mineral content between vegetables grown on widely differing soil types has commonly been misquoted as evidence for the benefits of organic methods. Some reports on qualitative differences, such as flavour in potatoes, can be attributed to differences in dry matter concentration and can be associated with the growing conditions, principally the supplies of water and nitrogen. There, the preferred conditions are as easily provided in conventional culture as in any other. There are many factors, environmental and cultural, that influence the nutritional composition of produce and that are not unique to either cultural system<sup>12</sup>. It is, at best, confusing to try to credit those effects to organic cultivation. Other assertions include that organic food tastes good, is nutritious and is produced without chemical pesticides or synthetic fertilisers. Leaving aside the question of pesticides, there is no difference between the protein and other nitrogen in conventionally and organically grown food. As regards nutrition, there is nothing wrong with synthetic fertilisers. The House of Lords Select Committee<sup>13</sup> found no evidence for or against the safety of organic products. Conventional and organic are equally safe. Further, the evidence given to them by the British Nutrition Foundation was that "the nutritional value of organic crops is likely to be the same as that of conventionally grown crops"<sup>13</sup>. The Select Committee emphasised that the organic label certifies that a product has been produced in a particular way; it is not that it has certain desirable qualities. Organic standards are based on the method of production, not on the characteristics of the finished product. They recognised that, in purchasing organic food, consumers may be expressing preferences other than the content of the food itself.

Consumers should beware of mission-directed disinformation from pressure groups. That was the assessment by the American Council on Science and Health, a consortium of over 250 leading scientists and physicians, on a report on pesticide residues on fruits and vegetables by a concern called the Environmental Working Group (EWG)<sup>14</sup>. In that report the EWG had excited fears over residues that led to the withdrawal of fruit from school menus. Yet the thresholds used were the official 'reference doses', only 1% of the level that should trigger questions about the source, and a smaller fraction still of the permissible dose.

Organic food is guaranteed free from genetic 'tampering'<sup>7</sup>. This was not part of the original principles and opposition to genetic modification appears to be a hitchhiker or a stowaway cadging a ride on a respectable movement. The matter will be considered later.

The Soil Association has adopted six criteria for the assessment of the quality of food - Sensual, Authenticity, Functional, Nutritional, Biological, and Ethical - to define a holistic approach. Such criteria defy the inclusion of material that is not *a priori* part of the organic system.

**Nitrate in water** Water leached from organic farms has been reported usually to contain less nitrate than the EC nitrate limit of 50 mg / litre although, in MAFF projects NT1313 and OF01410, the limit was sometimes exceeded<sup>4</sup>. That claim is not entirely borne out by the data from those projects, Table 3.

A similar statement could be made about conventional farms. Indeed, in those projects, comparison with conventional arable and grassland farms over the same period showed that nitrate losses from organic and ordinary arable fields were similar, although losses from conventional, intensively managed leys, including the ploughing out stage, were said to be higher than from organic leys. Neither details of the conven-

Year		Crop (mg	Mean nitrate/ litre)	Range		
199	93/94	Ley Arable1 Arable2+	20 68 26	0.4 - 25 34 - 112 8 - 58		
199	94/5	Ley Arable1 Arable2+	23 84 56	0.4 - 138 12 - 126 7 - 102		
199	95/6	Ley Arable1 Arable2+	45 105 113	1 - 108 8 - 201 44 - 368		
rable 1, first after ley; Arable 2+, all subsequent arable crops						

after the first.

**Table 3** Nitrate in soil water from the organic farms<sup>4</sup>.

tional rotations used for comparison nor the data on nitrate leached from them were given in the published report<sup>4</sup>. However, nitrate leaching in the two systems was said to be highly variable and the data shown (Table 3) is most revealing. Had the data come from a conventional system, one could well have inferred that there were strong arguments for reducing the inputs of fertilizer nitrogen. But that cannot be said of an organic system. Instead, we are left with the conclusion that the supply of nitrate was not at all controlled in the organic system and was not at all well matched to the demands of the crops being grown. It is striking that nitrate in the soil water was not highest after the ley, the 'fertility building phase', but after one or two or more arable crops. Clearly, the more extreme losses of nitrate should be avoided. Whether this can be achieved within the presently defined organic system has still to be proven. The balance of environmental advantages and disadvantages in the organic system is not clear. The House of Lords Select Committee on the European Communities did not accept that organic farming is the only way to achieve environmental and other benefits 15.

**Economic aspects** The economics of the organic approach are not really a concern of this review of organic farming but they cannot be ignored. It was reported<sup>4</sup> for MAFF Project OF0112 that gross margins, following conversion, had been consistently greater than for conventional crops and, even when projected over a full rotation and to a farm scale, the organic rotation had been significantly more profitable than the conventional rotation every year. The CWS study over 8 years concluded that, 'Both the mixed and all-arable organic systems were only slightly less profitable than the conventional farm data comparisons'<sup>16</sup>.

Currently, organic farming in the UK is predominantly on mixed and livestock farms in the West and North that produce animal manure. If the demand for organic arable and vegetable products continues to increase then it is likely that more farms that are currently all-arable will be considered for conversion<sup>4</sup>. These will face particular problems in maintaining soil fertility unless they become mixed farms with all the investment in infrastructure that would entail. The 'balanced' rotation envisaged for organic farms typically includes 2 or 3 years of grass-clover ley in a 5- or 6-year rotation. If the farm does not carry livestock, that land is, essentially, set-aside. True, none of the costs of producing a crop on that land are incurred but neither does it yield. It does not contribute to the income of the farm in those years and so the production from such a farm, as a whole, is halved. Suddenly the economics of the operation seem much less favourable. The House of Lords Select Committee on the European Communities rejected the idea of sustained subsidies for organic farming<sup>15</sup> but did commend continued financial support for conversion to organic farming<sup>17</sup>.

**Other environmental issues** Organic farming is claimed to be better for the countryside. For example, birds and other wildlife are a valued part of organic farming. It is a matter of record that less intensive application of conventional methods achieves the same results. Lapwings thrive on permanent pasture. So, increases in their populations, claimed for organic farms, reflect the balance between extensive and intensive agriculture, not an effect of organic farming per se. Several witnesses to the House of Lords Select Committee held that increases in biodiversity result from identifiable changes in management that could be implemented on conventional farms<sup>18</sup>. Recommendations on the treatment of hedges similarly can be accommodated within conventional systems and often are. It is a mistake to classify 'conventional' farms uniformly or even simply to divide them between allarable, mixed, and livestock farms. There is a range of levels of environmental awareness in their management. Conventional farms can be, and often are, managed in ways that provide the benefits to wild life claimed by the organic movement 18.

**Organic standards through the EU and elsewhere** The standards set by UKROFS require that the crop rotation (and therefore, crop nutrient supply) be based on a balance between crops that build fertility (i.e. legumes, normally grass/clover mixtures) and those that exploit it. The Soil Association declares in

its standards<sup>7</sup> that 'Brought-in manures or plant wastes from non-organic sources must not form the basis of a manurial programme, but should be adjuncts.' Yet there will be little of such materials available from organic sources as these are intended to run 'in balance' and should not be producing exportable wastes. Public controls on what may be fed to livestock and the protection of the public from residues in meat should mean that dung from a beast fed on an 'organic' farm is much like that from one fed on a conventional farm. Certainly, the differences between types of animal manure - poultry, pigs, and cattle - are far greater than those between manures from the two systems<sup>19</sup>. There seems to be little justification for this stance other than refusal to connive at another's spreading the resources of his farm. It is not clear that other European countries share these scruples. In the Netherlands, there is a much greater concern with the rational use of manure that is recognisably in surplus (at least locally) and that each farm should have a balance of inputs and outputs of each of the principal nutrients. While Dutch agriculture is being restructured, it is a requirement that animal producers should either have the land to take up the waste or have a contract from another farmer to use it. The sale and export of manures is encouraged. The USDA, in trying to define organic production, specifically includes off-farm organic wastes but whether or not those wastes are 'organic' in the sense used by the organic farming movement is unclear. The contrast between what the Dutch see as an evolution towards ecological agriculture $^{20}$  and the strict self-sufficiency of the organic system operated in the UK is striking.

### The problems

**Sustainability** Although it is relatively easy to describe goals for a more sustainable agriculture, it is more problematic to define

sustainability which is a complex and contested concept. To some, it implies persistence and the capacity for something to continue for a long time.

To others, it implies resilience and the ability to recover from imposed difficulties. Applied to the environment, it involves actions that do not damage or degrade natural resources. Others see it to mean that developmental activities simply take account of the environment. In any discussion of sustainability, it is important to clarify what is being sustained, for how long, for whose benefit and at whose cost, over what area, and measured by what criteria. Answering these questions is difficult as it means assessing and trading off values and beliefs<sup>3</sup>.

What do we mean by sustainable? All the food and other products taken from the land represent an abstraction of resources. Unless these are replaced, that land will become depleted and infertile. So, both organic and conventional agriculture must look to what resources are drawn from the land and how these are to be replaced. The principal commodities taken from the land are water, carbon and energy. These three are renewable. The water is replaced by rain and the amount of water that is taken off in agricultural products is a very small fraction of the total throughput in the system. Energy from the sun is fixed during photosynthesis in which growing plants assimilate carbon from the atmosphere. The ability of plants to fix carbon and energy is dependent on the fertility of the soil and its physical properties. The organic matter in the soil influences these and so it is a legitimate concern that an adequate proportion of the assimilated carbon should be left in the soil. The supply of water as rainfall may be inadequate for maximum crop production, and then irrigation may be considered. Unless the irrigation water is drawn from on-farm reservoirs, filled by winter rain, the practice of irrigation is arguably not strictly sustainable; but this has not yet been considered as an issue by the organic movement.

The main concerns over sustainability must lie in the ability to replace the nitrogen and other mineral elements that are taken from the land in a crop. Nitrogen and some other minerals are replaced from the atmosphere but not at rates that even approximate the rate of abstraction in a crop. So, the fixation of atmospheric nitrogen is in the order of 10 - 80 kg N / ha / y over most crops and 80 - 280 kg N / ha / y over a

clover-rich sward. But a well-grown crop of potatoes (60 t / ha) takes 160 kg N / ha off the field in the tubers and a 5 t / ha crop of spring barley would remove about

85 kg N / ha in the grain and perhaps 40 kg N / ha in the straw. From published figures of the mineral composition of potato tubers, it is a simple matter to calculate that a crop of 60 t / ha of potatoes removes 29, 338, 12, 4, and 5 kg per hectare of P, K, Mg, Ca, and Na, respectively, in the tubers. These minerals are not readily replaced in rainfall (Allen reported<sup>22</sup> average annual deposition in rainfall over seven sites to have

'Attempts to define sustainability miss the point that, like beauty, sustainability is in the eye of the beholder ...' A. Campbell <sup>21</sup> been 0.5, 4.0, 4.1, 11.4, 33 kg / ha of P, K, Mg, Ca, and Na, respectively, and 14 kg N / ha) and the growth of green manures only serves to cycle them.

"Sustainable agriculture should not imply a rejection of conventional practices but the combination of the best opportunities from modern science with a readoption of traditional opportunities to conserve resources. The two themes need not be incompatible". (Paraphrased from Pretty<sup>3</sup>).

Crop nutrition Is organic cultivation an environmentally friendly and effective agronomic system in which all resources are used effectively or are some wasted? Organic wastes should be incorporated into the soil directly after application. If this is not done then significant quantities of nitrogen can be lost to the atmosphere as ammonium and as nitrous oxide  $(N_2O)$  which will not only be losses from the system but are both atmospheric pollutants. In addition, the recommendation<sup>7</sup> to compost manures before using them is a practice that ensures significant loss of nitrogen to the atmosphere as ammonia. It is ecologically unsound. The maximum amount of the nitrogen in animal wastes is retained where slurry is placed directly into soil that has a growing green crop such as pasture. This is the required procedure in the Netherlands, in contrast to the common British practice of spreading slurry or manure on the surface for later incorporation.

When fresh manures or harvest residues are ploughed in, a proportion of the nitrogen content is readily mineralized to nitrate and this occurs within only a few weeks<sup>23</sup>. The remainder becomes available slowly over a period of years. The nitrate is immediately available for uptake by a crop, immobilization, denitrification, or it may be leached. Depending on the time of incorporation, more or less of the nitrogen in the manure can be available to the following crop.

How can one ensure that the nutrients are available to the crop at the correct time, and that mis-timing does not cause either environmental damage or reduction in crop yield and quality? The timing of tillage and the application of manures are central to the phased release of mineralised nitrogen. The rate of mineralization of organic matter in the soil is enhanced by cultivation, which should be timed so that the most nitrogen is provided shortly after emergence, when it is required by the crop. An inadequate supply of nitrogen during canopy expansion results in poorer interception of light and lower yield. Late mineralization of organic nitrogen to available forms, as happens after the harvesting of root crops or autumn ploughing, can result in losses through leaching.

The logistics of controlling the time and amount of ammonium-nitrogen released from the complexity of soil organic matter, and its subsequent conversion to the mobile nitrate-nitrogen, is not a trivial task and is a problem that is common to all husbandry systems.

It is likely, therefore, that computer-based decision support systems will play an increasing part in land management. For example, a package called MAN-NER (MANure Nitrogen Evaluation Routine) has been developed by ADAS with support from MAFF (Project No. NT1423) that uses a few simple inputs to characterise the organic matter being added to the soil. It then estimates losses by volatilization of ammonia, and leaching of nitrate, then the mineralization of manure N and, finally, the amount of manure N that will be available to the crop. Packages such as this will allow improved use of organic manures and a rational way to combine organic and bagged fertilizer. It is naïve to consider that a system that relies on the use of materials that break down slowly will allow better control of supply than one that uses a mixture of slow turnover and rapid correction.

**Pests** All crops can be attacked by pests and diseases so that the general expectation is for crops to suffer where chemical controls are removed. However, other management options may be available depending upon the crop and the pest or disease. Each has to be considered as a special case. Only a few will be considered here.

NEMATODES Nematicides are amongst the most toxic pesticides used and, because they have to be applied to soil, their rates of application are also high. In practice, a nematicide such as aldicarb is usually safe for people because of its restricted availability, the methods for its incorporation that prevent people coming in contact with the product, and because it rapidly degrades in most soils to harmless compounds. However, it is toxic to other soil animals, e.g. earthworms, and so has undesirable effects. Other soil nematicides or fumigants such as methyl bromide are even more undesirable.

So what are the options available to limit the effects of nematodes?

Although very damaging in some countries and although they occur in c. 50% of UK cereal fields, cereal cyst nematodes only occasionally cause damage

in the UK. Here, two fungi control it, one of which is almost specific and the other is a facultative egg parasite. These biological control agents increase and become suppressive following repeated cereal cropping. It seems likely that many other potentially damaging, mainly ectoparasitic, soil nematodes are kept in check by a whole complex of parasites and predators about which we know very little.

That is an example of a **biological control** that is effective without human intervention. However, in general it is extremely difficult to make biological control work in soil because of the complexity of the soil environment. There are problems in introducing the control agent, and once introduced it has to compete with the multitude of other organisms present. It has to persist and increase, and it has to be effective. Ideally, it needs to be specific to the pathogen against which it is targeted, and it needs to be safe to use. The case of control of the cereal cyst nematode is the exception rather than the rule.

Management by control of the **rotation** works for some nematodes, such as cyst nematodes with narrow host ranges, but not for others. This method of control requires a knowledge of principal and alternative hosts, rates of population decline when non-hosts are grown and of increase when hosts are grown. For other nematodes with wide host ranges, the position is even more difficult.

Some work has been done at SCRI on a specific bacterial parasite *(Pasteuria penetrans)* of the root-knot nematode *(Meloidogyne)* in an EU-funded project. Some soil types are unsuitable for its deployment but, even in those that are suitable, it is rarely suppressive. However, massive increases in soil populations of the bacterium and impressive suppression of the nematode have been observed where the gene pool of an indigenous strain has been enhanced by the introduction of an exotic one. Understanding the genetics and dynamics of such systems is not trivial, but it is possible that they could be developed for a few defined cases.

With species such as potato cyst nematode (PCN), where egg hatching is involved, **trap cropping** can be helpful but it requires a thorough knowledge of the biology of the pest, and may not be possible in many situations. It is, in effect, the mechanism that allows short rotations on land used for the production of early potatoes, where the crop is harvested before the nematode has time to complete its life-cycle. In some circumstances, **physical** control can work. At mid- to low-latitudes the most promising method is solarization but that is just not an option in the UK. Flooding, where possible, could be used to reduce numbers of pests but would also have deleterious effects on the beneficial biota and on soil structure.

The remaining choices are the use of resistant varieties of crops and the use of 'integrated pest management'. Resistance is generally seen as the long-term solution to pests and diseases. However, the goal of producing a variety that has the nutritional and culinary qualities that the market wants and that has resistance to all the threatened pests and diseases is unlikely to be attained in the foreseeable future. Certainly, not by conventional breeding. Producing resistance to even one pest is a major task although the rewards are considerable where it is achieved. It is the most cost-effective solution and involves no use of agro-chemicals. The potato variety Maris Piper, and similar ones, resistant to Globodera rostochiensis, the vellow PCN, gave enormous benefits to potato farmers in the UK during the 1970s and 1980s. Unfortunately, most farmers ignored the warnings of nematologists and did not integrate that resistance effectively with rotation, use of nematicides and an alternation between susceptible and resistant cultivars. The result has been that the virulent white PCN, Globodera pallida, has selectively replaced the yellow form in a very short time.

SCRI is heavily involved in studying sources of resistance in the host, characterising races of the nematodes for components of virulence, and the interaction between host and nematode. Activities to integrate that knowledge in mathematical models indicate that the white species, *G. pallida*, can be almost impossible to control without integrating resistance into a strategy which also includes long rotations **and** the use of granular nematicides.

Some level of **integrated control** is practised by almost all farmers, organic or not, because most use rotation. However, for pathogens such as PCN, proper control is not possible without the integration of two or more methods unless rotations are to be extremely long (>12 years). This will be discussed further under 'Opportunities'.

APHIDS AND OTHER INSECTS Aphids are vectors of viral diseases. In seed crops, therefore, the threat that they pose to the value of the crop is out of all proportion to their numbers. Even in the north of England and in Scotland where climatic conditions delay the appearance of numbers of aphids, growers depend on the use of chemical sprays to prevent loss of seed crops of potato. Aphids can form serious infestations in crops of both peas and beans that may even lead to the direct loss of the  $crop^{16}$ . Yet there is no effective treatment available in the organic system. An example of the potential for a low input, biological control in this area is described under 'Opportunities'.

SLUGS Slugs are favoured by weedy conditions, a likely circumstance in organic culture. Some varieties of potato are more resistant to slugs than others but, in all cases, slugs can make large amounts of tubers unsaleable. There have been cases reported of organic cereal crops being lost to  $slugs^{16}$ . Again, there is no effective treatment for field crops in the arable system.

**Disease** Most of the general observations on pests also apply to fungal and bacterial diseases of crops. Approval for the use of Bordeaux mixture in any crops will be withdrawn by the EU from 2002, so that the organic system will be left with few means other than genetic resistance to combat disease. This is discussed further in the next section. Zwankhuisen et al.<sup>24</sup> investigated the origins of outbreaks of late blight of potato in the Netherlands. They found that 74% of the early outbreaks were associated with nearby cull heaps, etc. Infected seed tubers and volunteer plants were of minor importance. Later, in mid-growing season of a year favourable to the spread of late blight, they found that infested organic potato fields became a secondary source of infection. In the Netherlands, the foliage of organic crops has to be destroyed by flaming immediately after the first appearance of the disease in order to prevent dispersal to neighbouring fields, to reduce the risk of oospore formation and to avert the infection of seed potatoes. There is a double message in this. One is that organically farmed potatoes are more prone to late blight and significantly increase the infection pressure on neighbouring crops. The other is that the moderate success to date in avoiding late blight in organically farmed potatoes is attributable to their low density - and, possibly, the use of Bordeaux mixture. They are surrounded by protected, clean, conventional crops. In this the organic growers are not unlike those parents who elect not to have their children vaccinated against a disease. They are, in effect, reliant upon the good health and hygiene of their neighbours.

Weed control Weeds pose the greatest challenges on some farms  $^{16}$ . The need for a number of cash crops

in the rotation leads to problems with both annual and perennial weeds. Extending the ley or green manure periods would reduce the weed problem but also the returns. Techniques that are available in an arable rotation include stale seedbed (not quite as stale as practised by conventional farmers), adjustment of sowing times and rates, and mechanical methods but these last are either laborious or expensive in energy.

### The contradictions - Environmental Friend or Foe?

Pesticides based on bacteria and viruses offer promising opportunities for selectivity in tackling pests and in reducing pollution<sup>3</sup> - p. 103. The greatest successes so far have been preparations derived from Bacillus *thuringiensis*  $(Bt)^{25}$ . The bacillus produces a soluble crystalline toxin that paralyses the gut and mouthparts. The toxin is effective against a range of insects, particularly certain lepidoptera, but is harmless to plants and to humans. It is used in a wide range of pesticides and the bacterium itself is used for pest control in organic systems<sup>25</sup>. The toxin of *Bt* is produced by a single gene which has now been cloned and inserted into non-pathogenic bacteria that colonise plant roots, and also directly into some crop plants such as tomato. The potential for engineering plants to contain their own defensive compounds in this way is considerable. The Soil Association's standards<sup>7</sup> accept *Bt* as a chemical but not the insertion of the *Bt* gene into the plant itself. Yet many crop plants produce localised toxins. For example, potato produces high levels of glycoalkaloids in its leaves as a defence mechanism, but not in the tubers unless they are allowed to 'green'.

In the report on a recent MAFF-funded project (OF0112) it was reported<sup>4</sup> that "The only pesticide applied was Bordeaux mixture. This copper-based fungicide was applied to potatoes up to three times a year....". The justification for the use of Bordeaux mixture - a simple solution of inorganic salts - in 'organic' systems appears to have been that it was hallowed by time. In fact, it is not at all environmentally friendly and copper is toxic at the levels used in Bordeaux mixture - that is why it was devised. Bordeaux mixture is a known molluscicide, it repels slugs and snails and is toxic to earthworms, and its use within the EU will be banned in 2002 - nothing to do with organic farming, rather the environmental concerns of the 'conventional' farming community.

A full account of the use and toxicology of copper sulphate is to be found at the web site: http://pmep.cce.

cornell.edu/profiles/extoxnet/carbaryl-dicrotophos/ copper-sulfate-ext.html

Conventional agriculture has reached its present level of production by adopting the use of a battery of agrochemicals - fungicides, insecticides, nematicides, herbicides - and these are among the products that have been most opposed by the organic farming movement. Traditionally, plant breeding for resistance to diseases has been seen as an important means for agricultural progress and reduced reliance on agro-chemicals. The modern techniques, familiarly called genetic engineering or genetic modification, offer the prospect of introducing resistance to pests and diseases more effectively and more quickly. After taking evidence from a wide range of experts and interest groups, a select committee of the House of Lords reported<sup>26</sup> that, "..biotechnology in general and genetic modification in particular offer great potential benefits to agriculture, industry, consumers and even to the environment. The fruits of the technology should be available to our farmers, manufacturers and consumers. These developments have to be surrounded by an assessment of risk (and, where necessary, its management), ....." Yet the Soil Association, in its evidence $^{27}$ , described the introduction of genetically modified plants into United Kingdom agriculture as the "most serious threat ever to the objectives and progress of the organic farming movement in developing and introducing viable systems-based approaches to agriculture". This opposition has to be recognised as a contradiction of the underlying principles of the organic movement. No-one objects that there is no food for the caterpillar of the cabbage white butterfly where cereals are grown. Why should they complain if they couldn't feed on a cabbage crop? They may still feed on wild relatives of the cabbage. Where is the ecological benefit of rampant late blight of potato? No other organism feeds on the fungus causing the disease. Genetic engineering would appear to be compatible with the principles of organic farming even if the proponents of the movement do not presently recognise it as such. The relation between genetically modified organisms (GMO) and organic farming will be discussed again in the next section.

#### The opportunities

**Genetic modification** For over 70 years, plant breeding and selection for resistance to diseases has been seen as an important means for agricultural progress. This strategy has had some successes but in many cases, for example rice blast in rice and late blight of potato, disease resistance in the crop has been relatively short-lived and the disease organism has mutated or been selected to overcome that resistance. If durable forms of resistance to any of the major diseases could be introduced into otherwise acceptable varieties by genetic modification, the saving in use of agro-chemicals would be immense.

The Soil Association has, however, set its face against the use of genetically modified crops in any form<sup>7</sup>, stating "4.303 Prohibited .. 4) Varieties of seed that have been produced using Genetic Engineering". There is no doubt, no equivocation, just straight opposition. In doing this, the Soil Association would appear to be opposing the very means by which many of its ends could be achieved. They should be encouraged to take a more positive role by participating in determining the standards that might be used to test for acceptability and safety of GM products. They should help to establish what is safe. The corollary, of course, would be that once there are agreed standards for testing, material that meets those standards would be acceptable.

At present, the Soil Association and its present allies consider that not only are GM crops unacceptable but also that no pollination of organic crops by pollen from GM crops is tolerable. More recently they have extended this objection to passive contamination with pollen from sexually incompatible species and the aversion extends to the inclusion of such pollen in 'organic' honey. The former point seems to be particularly illogical. Sexual barriers prevent the exchange of genetic information. The latter one can hardly be achievable given the foraging range of bees.

The zero-tolerance approach to pollen is clearly incompatible with the coexistence of GM and organic crops. The only way to achieve it would be to ban GM crops entirely - or to abandon organic farming. There must be other ways. For example, there are established tolerances for other kinds of contamination in organic products. Council Regulation 2092/91 allows 5% of non-organic ingredient in organic products, although a draft regulation proposes reducing this to 1%. Again, ACRE in 1998, considering a case involving organic maize, noted that the purity requirement for Basic Seed (the highest specification for maize seed) is 99.9%. This sets an upper limit on the purity that can be guaranteed for the crop. Therefore, pollination by GM pollen at a level much less than 0.1% could not reasonably be regarded as significant.

If a non-zero tolerance level were to become accept-

able, there would be scientific questions to be answered in determining what that level should be such as how compliance is to be verified, and what isolation or other measures are required to ensure compliance.

Non-zero tolerances are consistent with other aspects of organic farming. What often seem to be arbitrary rules can in many cases be represented as a compromise between what is considered desirable and what is practicable.

### Integrated crop management

MANAGING NATURAL ENEMIES - PREDATORS, PARASITES, AND DISEASES The use of natural enemies is commonly referred to as biological control and examples have already been described under 'Nematodes'. That can be further classified as 'classical', in which new or exotic natural enemies are released, and 'augmentation' that relies on improving or supplementing the existing control. There have been considerable efforts over recent years to develop effective biological control programmes<sup>28</sup>. Occasionally the results are spectacular as in the control of Opuntia with Cactoblastis cactorum. More usually programmes have moderate success and there have been more failures than suc $cesses^{29}$ . The principal difficulty is in maintaining the parasite or predator at levels that will keep the pest at an acceptably low level. For this reason, some of the most successful programmes for biological control have been against pests of glasshouse crops where the high level of environmental control coupled with containment and replacement favour the use of natural enemies.

An interesting example can be taken from another environment. Pigeon pea and cotton share a common insect pest *Helicoverpa armigera* that is highly damaging to both crops and that has developed a considerable amount of resistance to pesticides. To tackle the problem, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), in collaboration with national programmes and other research institutes, has been studying a naturally occurring viral disease, nuclear polyhedrosis virus (NPV). This is specific to *H. armigera*, and has been found to be 95% as effective as chemical insecticides<sup>30</sup>, giving low-cost control and an environmentally safe option for subsistence farmers who grow pigeon pea. Pigeon pea is also used as a trap crop, grown with cotton<sup>30</sup>.

TECHNOLOGY AND REDUCED INPUTS In the UK, evidence from growers is that if the timing of application is correct for fungicides on cereals, rates can be cut by

50 - 75% and still maintain yields (See Table 1). For example, a recent recommendation is that farmers should inspect their crops regularly and apply quarter rate fungicide mix when 75% of plants show at least one active spot of mildew<sup>31</sup>. Careful monitoring and sequential sampling for pests on brassicas has reduced the need for pesticides by 85%, while maintaining yields. In the soft fruit sector some growers have cut their use of fungicides to 12 - 25% of former levels after adoption of a range of IPM techniques<sup>32</sup>. However, these low-dose approaches do demand that growers monitor their crops intensively. In a sense, the two extremes of organic and conventional agriculture discourage thinking. Either you apply nothing (organic) or you apply the full dose to everything (conventional). A rational approach requires monitoring and decision making. The rewards can be considerable, both financial and environmental.

Patch spraying is a technique that similarly can reduce inputs significantly. Patch spraying needs a combination of regular field monitoring, whether done using modern technological capabilities such as remote sensing coupled with GPS or more simply from direct field walking, and modified spraying systems. The approach is applicable for control of both weeds and pests.

### Conclusions

Organic farming has the joint aims of being environmentally sensitive or correct and being sustainable. In order to promulgate those aims, it has developed a set of rules and standards to which its followers must adhere. There is very little derogation. As a result, organic farming does not require best use of the options available, but the best use of the options that have been approved. These options are usually more complex and sometimes less effective than conventional ones. Improvement of the options available to the organic farming movement will require scientific effort - it may also require some re-evaluation of practices by its adherents. Such science will also be relevant to conventional agriculture, because many practices are common to both organic and conventional farming and because the 'conventional' farmer is not inhibited from using 'organic' approaches. So, for example, a conventional farmer may conclude that the 'organic' approach is about right for pesticides and only half right for fertilisers, or whatever.

The philosophy of the proponents of organic farming presents a difficulty to the scientist. The organic movement, generally, resists comparisons between

adjacent and otherwise comparable plots of 'conventional' and 'organic' land, saying that the organic system has to be considered as a whole and that it is inappropriate to break down parts for examination. Yet, without such an analytical approach it is not possible to understand, or even monitor satisfactorily, the processes operating within the system. This philosophical disparity is at least a contributory cause for the lack of valid comparisons between systems in soil fertility, pollutants in soil solution, the value of the food produced, and others.

The organic farming movement presents a challenge to the scientist, who cannot - and would not want to abandon a scientific approach. We have to accept a philosophy that says, 'I don't want to do particular things.' The challenge for the scientist is to find a way of living beside, and working with, that system, while recognising that not all of its tenets are correct, and while identifying which of them are misguided, and enabling the improved application of those that are correct. Where the organic system does not conflict with science, there is no problem but it is possible to show, for example, that strict adherence to some principles such as sources of fertilizer, could be more harmful to the environment than other ways. The present lower productivity of the system should not present a conflict. It is simply the result of a constraint that the practitioners have put upon themselves in order to achieve a particular effect in their environment. While the intended effect is one that most people agree is desirable, there may be other, more direct means to achieve it. Where a scientist has particular difficulty is with the evangelising statements that the products of the system - food and fibre - are in some way 'better' than those from conventional agriculture.

We would like to be able to argue for a different route in some aspects, between 'organic' and 'conventional, high input' farming. An exemplary issue is the production of varieties that are resistant to pests and diseases - particularly where the adoption of those varieties would lead to the reduction or even elimination of particular chemical inputs. Instead, the pharisaic attitude of many in the organic movement leads to feelings of frustration in some scientists who can see the applicability of their work to the system, yet have it rejected. The products of biotechnology in general and of genetic engineering in particular are among that work.

A recognised major disadvantage of organic farming is the likelihood of reduced output per hectare. The extent of this reduction can be limited by careful rotational planning, strategies for efficient manuring and supply of crop nutrients and by attention to detail in the husbandry practices adopted for control of weeds, pests and diseases. This is another case where a flexible approach to solving problems by, for example, combining modern technology for monitoring and positioning with selective use of agro-chemicals, is capable of transforming crop production while minimising inputs.

A scientific base is essential to make best use of the available measures for production and control of problems in conventional agriculture, and even more so in organic agriculture. Just as the consuming public has a right to a choice in the products that it will use, based on professionally produced information, so the farming public has a right to scientific and technical support for their agricultural systems, which ever is used. But they only have that right where they are prepared to accept, for a time, the validity of its products. All good science accepts that its results may later be proved false. Where an approach to agriculture, or life, rejects the lessons of science a priori, then it disqualifies itself for that support. The organic movement should be encouraged to be less defensive of its standards and less prescriptive in their application. It should be encouraged to recognise the contribution towards its wider aims that is offered by modern science. Equally, scientists must recognise the opportunities for interesting science offered by the constraints of minimised inputs and the principle of sustainability. SCRI has a mission in these areas.

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