# SESSION 7B

# PEST AND DISEASE MANAGEMENT IN ORGANIC FARMING

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# Organic agriculture and GM crops

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## ABSTRACT

Organic agriculture is a proven and effective system of sustainable agriculture. Its sustainability is fundamentally dependent upon functional biodiversity (appropriate varieties and breeds, rotations, inter-cropping) and on the natural environment (beneficial organisms and other ecological services). In contrast, conventional agriculture is a linear system that provides greater productivity but at higher costs (fossil energy use, soil degradation, pollution). This system uses inputs to try to control environmental variation, often concentrating on specialised crops. The initial phases of GM technology appear to be designed to further this linear approach. This has implications for the integrity of living organisms, maintenance of the natural environment and food quality.

## INTRODUCTION

Farming systems can be based upon either a linear (most arable production systems including ICM) or a network model (organic systems) (Atkinson & Watson, 2000). Organic systems depend upon the management of ecological processes that allow the crop to be grown successfully despite the presence of organisms that, in other systems, would be likely to have unacceptable adverse effects on economic production (i.e. diseases, pests, weeds). Indeed, the biological complexity of the organic system allows it to deliver biodiversity as a co-product not just as a by-product of the system (Wolfe *et al.*, 2002). Organic systems also emphasise the social consequences of farming, such as employment. It is also now well-established that organic systems enhance soil quality (Maeder *et al.*, 2002), promote efficient energy use (Cormack, 2000) and encourage biodiversity (English Nature, 2000).

Conventional agriculture, on the other hand, can be highly productive but utilises a linear and production-orientated approach that has resulted in a number of problems e.g. soil degradation, excessive fossil energy use and depletion of biodiversity. Attempts to deal with these problems have followed this linear approach including the recent introduction of GM crops.

The development of molecular biology created a revolution in science that has already had a profound effect on our understanding of life and the natural world. Scientists engaged in this process have raised many novel suggestions for applications of the technology that create new opportunities and solve old problems. However, it has become clear that considerable time and effort is needed to understand both the advantages and disadvantages of these technologies.

Biotech companies have developed transgenic plants and animals to try to improve conventional agriculture. However, many criticisms and concerns have been raised because of the fundamental nature of the modifications, the uncertainty that multiple and even targeted insertions may have on the recipient genome and the open nature of the agricultural environment. The organic sector is concerned about these issues, because its basic philosophy is concerned with the integration of healthy soil, healthy plants, healthy animals and healthy humans. However, some issues are emphasised more from the organic perspective than from the more general view. Here we concentrate on these aspects and try to develop some of the reasons for the refusal of the organic sector to take up what some regard as exciting new technologies. It should be stressed, however, that organic agriculture welcomes the use of molecular biological approaches for developing our understanding of the living world and in helping with agricultural development in a multitude of other ways.

## THE WHOLE ORGANISM VIEW

### Integrity of organisms

As a starting point for the development of systems, organic agriculture accepts the wide range of organisms that have evolved through natural selection or that have been bred by near-natural methods. Such whole organisms are respected for their intrinsic value, not only because of their existence, but because we have remarkably little understanding, even today, of the range of properties and potentials that they possess. Living organisms have many different levels of complexity of organisation from gene to cell to organ to whole organism, with a range of emergent properties added at each level of complexity. Because of our imperfect understanding of these subtleties, the organic view is that the organisms that we use, consciously or unconsciously, in agriculture should be allowed to maintain their integrity. This applies to breeding for agriculture in the sense that the technologies used should also, as far as possible, maintain integrity. Those involved in genetic modification take a more Cartesian view proposing that the fundamental parts of the organism can be treated as building blocks to be used in any desired arrangement either within or among species. This is supported by the suggestion that there are numerous examples of natural gene exchange across species boundaries. However, the scale of such exchanges is small and the opportunities are limited by proximity; they are the exception not the rule. The problem with the current GM approach is first, that the opportunities for modification are thought to be unlimited (e.g. flounder genes in strawberries) and, that when a GM plant leaves the laboratory, the scale of spread of these unlikely combinations becomes possibly vast and non-retractable.

The organic view is a precautionary one, to maintain, as far as possible, the integrity of the individual and the subtleties of its organisation. This view is held because of its perceived importance for agriculture and ultimately for human society.

### Substantial equivalence

Another, related, ethical issue is raised by the question of substantial equivalence. The concept of substantial equivalence was developed as a pragmatic approach to the problem of defining which transgenic organisms could be registered for release, and which not. On the Cartesian view of limited interaction of the introduced gene with the remainder of the organism, the assumption was that a GM organism that resembled closely its 'normal' parent except for the newly introduced single function, could be released for field trialling. The problem lies in defining the resemblance because, inevitably, it will be based on a relatively small number of characters (even the potential for pleiotropy of the introduced gene construct may not be fully considered). Moreover, there is the possibility of interactions, which may depend on undefined environmental conditions, between the introduced gene or function and the remainder of the organism. Such effects may not be recognised in a limited laboratory or field trial framework over a short time span. Over a large scale and long time period, unpredicted instabilities and other effects might develop either directly or through hybridisation of the substantially equivalent plant or animal with others.

The free market view within WTO would argue that transgenic foods, having been agreed to be substantially equivalent to non-GM foods, should be introduced and preferably without the need of labelling. European and the Cains Group views of the activities of consumers or citizens differ and this difference is frequently at the core of WTO disagreements.

## CURRENT AGRICULTURAL ISSUES

### Prevention or cure?

A basic precept in organic agriculture is that of prevention rather than cure. The agricultural system is designed to try to prevent, for example, pests, diseases and weeds from increasing to problem levels, usually through the use of biodiversity. The few permitted 'pesticides', including Bt (*Bacillus thuringiensis*), are used as a measure of last resort and only when all other means, including prevention, have failed (Anonymous, 2000).

This approach is different from that of the biotechnology industry and conventional agriculture which tries to identify large-scale problems and then to design a 'silver bullet' cure which can be used on the largest possible monocultural scale in order to re-coup investment costs and provide an attractive return for the company and its shareholders.

In practice, most of the few characters developed so far for GM application are concerned with cure rather than prevention, which, by continuous, monocultural use, select for a response from the target organism and/or transfer of the character in question to other species. One example is the use of different herbicide resistant forms of oilseed rape in Canada which has led to the increase of weed rape with different combinations of herbicide resistance characters (Hall *et al*., 2000) either in the existing population or in the soil seed bank. In the case of Bt transgenic crops, the gene is present and potentially expressed by the crop at all times and in all tissues. Therefore the duration and type of exposure of insects (both target and non-target) to the toxin in the crop is different from that when the native organism is used as a control agent, and leads to stronger selection for pest resistance to the insecticide. Indeed, there is evidence from Australia of the expected resistance response of target cotton pests to the use of Bt toxin expression in GM cotton.

## Biodiversity and gene flow

A major issue is the consequences of the flow of genes from transgenic crops to both wild species and to other non-transgenic crop cultivars of the same species (Dale *et al.*, 2002; Ellstrand *et al.*, 1999). Of the GM crops that are currently being trialled in the UK (oil seed rape, sugar beet and maize), only oil seed rape and sugar beet have native wild relatives. There is evidence that genes have moved from oil seed rape crops into native weedy relatives (Dale *et al.*, 2002).

There are also examples of multiple crossing resulting in a hybrid possessing more than one GM trait (Hall *et al*, 2000). The impact of transgenic varieties pollinating other cultivars is currently unknown but it is problematic in relation to the quality control of non-GM products. This is of particular concern to organic farmers with their need to use organic seed and cultivars that have to be GM free to maintain their organic status. The contamination of Canadian oil seed rape seed stocks demonstrates the difficulties in maintaining seed purity. From the information already available there can be no doubt that cross-pollination will occur and so the key question is the extent of separation that will be needed between GM and organic crops to ensure that cross-pollination does not occur (Moyes & Dale, 1999; Dale *et al.*, 2002). These separation distances are currently under debate (AEBC, 2001) but it is apparent that it is not a simple matter of setting a single distance. A range of factors will affect separation distances such as crop species, husbandry practices, sink and source size, topography and prevailing weather conditions. Setting appropriate distances will be critical in allowing organic and other non-GM crops to maintain the purity needed for certification and export so as to meet the needs of that part of the public wanting non-GM food products. Current field scale trials designed to assess the environmental impact of GM crops will ultimately require a judgement on ecological significance.

## Ownership and responsibility

The introduction of any new technology will result in problems not envisaged at the time of the introduction. But who is responsible for any damage caused? In the past, industry has been unwilling to accept the financial responsibility for addressing the downsides of its activities and products. The case histories of thalidomide, asbestos and DDT illustrate the point. The potential problem for the biotech industry, or for farmers, is considerably worse in relation to the question of recovery from any mishap or error that occurs as a result of release of a GM crop or variety because there can never be any certainty that it, or its constituents, have been fully withdrawn, since agriculture is open to the natural environment. Anecdotal evidence suggests that insurance companies are not interested, so is it inevitable that the ultimate responsibility will rest with governments and taxpayers?

# FUTURE AGRICULTURAL ISSUES

## Organic agriculture

Among other developments, there is no doubt that the future of organic agriculture will be dependent on the production of plants and animals appropriate to organic systems. This is because there is accumulating evidence for the inappropriateness of current popular varieties and breeds selected under non-organic conditions. One outstanding characteristic of prime importance is the need for weed competitiveness in crop varieties. Organic agriculture is therefore in the process of defining criteria necessary first, to produce appropriate varieties, and second, to ensure that the methodologies used are consistent with the principles of organic agriculture (Lammerts *et al.*, 1999). One example is a DEFRA-funded project, which is developing a population breeding approach for wheat. The populations produced will form a genetic resource for all farmers but, importantly for organic farming, we will try to exploit this diverse material directly in organic wheat production systems.

Such approaches to breeding help to provide the biodiversity tools for direct use in organic agricultural systems, but, in addition, there is strong reliance on indirect biodiversity tools, for example, the soil microbial populations and the wide range of naturally-occurring beneficial organisms. For this reason, there is a deep concern in the organic agricultural community for the maintenance of the natural biodiversity that forms an intimate part of organic agricultural systems.

The kinds of multi-faceted system questions that concern organic producers, such as food quality for human health, weed control without the use of herbicides, or interactions of crop plants with the soil microbiological community, are simply not amenable to the current single gene applications of GM varieties. Moreover, even if GM varieties were acceptable in organic agriculture, it is doubtful if the major companies would be interested in being involved because of the complications involved in agricultural systems that depend, for example, on diversified rotational systems with mixed and inter-crop applications. Applying contracts to maintain seed or varietal purity would become a nightmare both for the company involved and for the farmer.

### Conventional agriculture

For the future, conventional agriculture is under increasing pressure to minimise its environmental impact in all directions. There is no doubt that GM companies are looking at a wider range of potential products than the current concentration on herbicide and Bt resistance. However, a simple increase in the numbers of traits that are developed for large scale use will inevitably increase the degree of risk. Of greater concern is a consideration of the kind of characters that are being proposed and developed: "The genes that catch my [Allison Snow] attention as an ecologist are anything that makes the plants bigger and healthier, or anything that would allow them to expand their range, like cold tolerance or drought tolerance or salt tolerance" (Holmes, 2002). Here, the ecologist is concerned with large-scale delivery of a change into the environment which cannot be recalled.

We have included a balance sheet for organic and GM intensive agriculture in Table 1 to highlight some of the differences that we believe will be important in future agricultural development, particularly with respect to global climate change. Our view is that the introduction of transgenic crops, unlike the development of organic systems, is likely to have a nil or negative effect on the relationship of agriculture production on climate change.

## GM AND FOOD

The impact of GM crops on the composition and quality of foods is for many the greatest area of concern in the hitherto unknown situation in which people feel increasingly remote from the origins of their food and food sources. Organic agriculture tries, in a variety of ways, from production to marketing, to engage with this problem. Relevant to this, Johns (1996) developed the thesis, based on evolutionary considerations, that such compounds are positively important in human as well as plant health, since they will restrict a wide range of fungal, bacterial and other organisms.

Table 1. Positive, reducing climate change impact, and negative, increasing GH gases, aspects of two contrasting farming systems a) an arable rotation employing GM crop varieties with resistance to broad spectrum herbicides and b) an organic system where 50% of the rotation contains arable crops.

| POSITIVE | NEGATIVE |
|---|---|
| **The Intensive Arable System** | |
| • Direct drilling will increase carbon accumulation in the soil surface.<br>• Direct drilling will reduce the energy required for cultivation.<br>• GM varieties with enhanced resistance to pests and diseases will require fewer pesticides and so reducing GH emissions during manufacture. | •<br>• Intensive systems maximise the proportion of carbon fixed partionined to edible products so reducing carbon storage. Intensive systems have shown reduced soil carbon.<br>• Being able to use herbicides at any time will increase their frequency of use, increasing demand and thus the carbon cost of manufacture.<br>• The herbicide resistances introduced to crops will be to older materials with higher application rates using more carbon in manufacture.<br>• New technology may allow non-arable land to be cultivated thus reducing carbon storage in soil and perennial vegetation.<br>• The fertiliser demands of intensive systems increases $N_20$, a high impact GH gas, emission. |
| **The Organic System** | |
| • The fertility building phases of the organic system increase the storage of carbon through much of soil profile.<br>• Crops with inherently high resistance to disease and which integrate into bio-diverse systems invest significantly more carbon in the root system leading to soil carbon accumulation.<br>• Minimising of external inputs, especially ones with high manufacturing costs, eg. pesticides, reduce the emission of C.<br>• The recycling of organic manures reduces the loss of $NH_3$ and $CH_4$ from animal manures..<br>• The conservation of nutrients through green manures which reduces winter leaching losses increase soil C storage and reduces the energy costs needed to remove diffuse pollutants from water. | • The need for cultivations will increase carbon release through the use of non-renewable fuels. |

However, the extent to which the properties of organic foods differ from those produced in other agricultural systems is controversial. The core element is whether there are properties of foods, important to health and wellbeing, which are not sufficiently well understood to permit appropriate measurements to be made and for risk to be assessed. The history of the discovery and measurement of compounds such as vitamins in food and their impact upon health would suggest that there remains much to learn about both food and food–health linkages. Many of what are now considered to be important components of food are relatively recent discoveries, as are their impacts upon health. Some of these are documented in Table 2. The recent discovery of antioxidants able to remove or protect against the impact of free-radicals supports this view (Ramirez-Tortosa *et al.*, 2001). And the discovery of important structural features of foods suggests that casual or accidental changes which might perturb important but uncharacterised factors should be avoided. It matters to remember that the absence of evidence is different from the evidence of absence.

Table 2. Significant discoveries relating to food and nutrition

| Date | Event | Importance |
|---|---|---|
| 1933 | Structure of Vitamin C | Scurvy |
| 1960 | Selenium in glutathione perioxidase | Function of heart muscles |
| 1970 | Fibre in diet | Anti-cancer |
| 1984 | Separate metabolic routes of Omega 3 and 6 fatty acids | Blood pressure |
| 1988 | BSE identified | |
| 1995 | Sitostanol | Blood cholesterol |
| 2000 | Anthocyanins in fruit | Anti-oxidant protection |

The husbandry practices involved in the production of organic crops and the processes which convert these to organic foods are of themselves likely to have positive effects on food quality. A major area of contention relates to the existence and significance of vitality and structure in food. Diagnostic tests (Pfeiffer, 1975) based on the energy and hydration changes that occur on the crystallisation of appropriate indicator compounds in the presence of food abstracts suggest that there are important properties of foods which are influenced by their means of production. These properties provide a major reason for organising the separation of organic and conventional crops.

## CONCLUSIONS

- Organic agriculture is a valid form of sustainable agriculture, well-recognised by the general public. Its development depends upon the integration of managed and natural biodiversity and is essential for the future of sustainable development.
- New developments in molecular biology represent an exciting prospect for many applications to extend our understanding of the natural world and for improving agriculture. However, the specific application in the form of GM crops and breeds raises a number of fundamental concerns, not least because the agricultural environment is open.
- From the perspective of organic agriculture, these concerns relate to the integrity of organisms, substantial equivalence, biodiversity and gene flow, and, perhaps the most important of all, to food quality.

- There is an urgent need to protect the needs of the large sector of the public which objects to the exploitation of GM crops and breeds either on ethical or practical grounds.
- Effective separation of organic from conventional-GM agriculture and of their food systems will be difficult. Even when separated, a key concern is that they will still share the same natural environment.

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# The role of functional biodiversity in managing pests and diseases in organic production systems

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## ABSTRACT

In organic agriculture, management of pests and diseases is part of overall system development. The basic tenet for the system is to develop healthy soil. This depends on the exploitation of functional biodiversity through the use of manures and composts within crop and animal rotations. Further improvement depends on wider exploitation of functional biodiversity, for example, the application, and integration, of novel mono- and polycultural methods, from crop variety mixtures to agroforestry systems. These methods need to deliver a range of benefits to the system as a whole, including stability and restriction of pests and diseases.

## INTRODUCTION

The recent modernisation of agriculture required many innovations to help increase productivity. Such innovations came mainly from readily available technologies, such as engineering and chemistry; relatively little was possible from ecology because of the slower development of understanding of this complex area of biology. Dramatic increases in gross production were achieved, but the massive changes in land exploitation combined with regular additions of large amounts of synthetic chemicals into the natural environment, led to significant and unexpected changes in the ecology of plants and animals. Problems arose, some of which are now familiar, others of which are, no doubt, still waiting to be discovered.

Some ecologists and agriculturalists felt that a better understanding of ecology should help to develop agricultural systems that are productive while avoiding major ecological problems. One approach was organic agriculture, which has gained a wide following, often because of the problems that emerged with intensive conventional production. More importantly, agroecology has shown that approaches developed in organic agriculture have often been appropriate to simultaneous improvement of productivity and avoidance of problems. Increasing support for agroecology should advance ecological agriculture thus replacing the need for external interventions, including synthetic chemical inputs. Not only would one layer of problems be removed, but there would be a significant reduction in the use of fossil energy, providing a positive contribution to the need to restrict global climate change.

## FUNCTIONAL BIODIVERSITY

### a) Within the soil

The most important concern in the development of organic agriculture was to develop healthy soils as fundamental to the development of agricultural systems buffered against pest, disease and other problems. A long-term study (Maeder *et al.*, 2002) of different aspects of soil quality compared soils developed from organic systems with those from conventional agricultural methods based on synthetic fertilisers and pesticides. The organically managed soils proved significantly more biologically active than the non-organic, with significantly less expenditure of energy in the farming approach. Yields were overall 20% lower in the organic systems, but this was probably more than offset by the improved sustainability of the organic systems, with the large energy saving (up to 55%) and a 97% reduction in pesticide use.

The range of organisms in the soil should be potent and continuously active in the innumerable interactions within soil food webs. This helps to ensure that the range of crop pathogenic organisms that are often present are restricted in their potential to increase. The heightened biological activity of organically farmed soils results from many positive factors other than the avoidance of synthetic fertilisers and pesticides. The principal factors are to rotate crops and animals, to feed the soil with composts and manures and to manage cultivations appropriately.

Crop rotation

Crop rotation is basic to organic systems and includes the use of catch cropping, cover cropping and green manures. Effective use of these methods leads to high diversity of the soil microbial flora and fauna whose composition is under continuous change. Although rotational systems were developed originally for direct nutritional benefit (for example, the use of legumes to fix nitrogen), weed control or economic value, increasing numbers of examples are emerging of the ways in which these systems can be important in disease and pest restriction.

One illustration of the value of rotations in disease control is where they have been neglected. Wheat and maize are both susceptible to *Fusarium culmorum* and *F. graminearum* which survive largely by overwintering on crop residues. During the 1990s in the mid-West of the USA, the crops were grown as usual with little or no rotation, and with minimum tillage to reduce soil erosion and conserve energy. As a result, there was no breakdown of crop residues leading to the build-up of massive amounts of soil inoculum. Disease-conducive weather then led to severe yield losses and, more importantly, mycotoxin contamination of wheat (McMullen *et al.*, 1997).

The length of the rotation can be the key factor in determining pathogen persistence (for example, Van Bruggen, 1998). Many pathogens overseason in the soil or on crop residues and there is a limit to how long they can survive in the absence of their hosts (e.g. *Sclerotinia sclerotiorum, Rhizoctonia solani, Fusarium spp. Pseudocercosporella herpotrichoides* and *Gaeumannomyces graminis)*. Often, a break of two to four years is sufficient to reduce inoculum to a level that will allow the production of a healthy crop. However, for safety in the system overall, it is essential to have rotations that last for a minimum of four to five years.

Influence of crop type in rotations

Particular crops can have specific effects in crop rotations. For example, Brassica crops such as mustard can reduce significantly potential infection by non-Brassica pathogens on non-Brassica crops that follow them. Kirkegaard *et al.*, (1996) showed how mustard cover crops could reduce take-all infection in subsequent wheat crops. There may be disadvantages, however, in that mustard may restrict infection of subsequent crops by mycorrhizal fungi (Karasawa *et al.*, 2001) which may themselves be involved in disease resistance (Vigo *et al.*,

2000) as well as moderation of phosphate availability. This may be offset by using varieties that are well-adapted to mycorrhizal infection, for example, some older wheat varieties appear to be better adapted in this way than are more modern varieties (Hetrick *et al.*, 1992). Among other examples, oats reduce *Fusarium* and other diseases of cereals when used as pre- or inter-crops (Vilich-Meller, 1992) and are allelopathic to weeds. However, the allelopathic effects and disease suppression may be variety specific (Elmer and LaMondia, 1999).

Composts and manures

Composts and manures added to soil are biologically active because of the range of microflora and fauna that they contain. However, Hoitink (1998) stressed that many factors must be controlled for composts to provide consistent effects. The raw materials, the composting process and the types of microorganism colonizing composts after peak heating are all critical.

Control of soilborne plant pathogens such as *Pythium* and *Phytophthora* spp. is common because of the activity of a broad spectrum of biocontrol agents present in most composts. In contrast, pathogens such as *Rhizoctonia solani* are controlled effectively by only a narrow range of such agents. Added biodiversity, in the form of inoculation with specific agents, could be used to overcome this deficiency if crop rotation alone proved inadequate.

The optimal approach to rotations, cover crops and soil cultivation is probably dependent on individual locations and systems. However, as knowledge of soil food webs and their interactions with plants increases, it should become possible to specify rotations, varieties and treatments more precisely so as to minimise diseases, pests and weeds. However, even this complex objective cannot be regarded alone; it has to be related to the major objective of optimising the nutrient budget of the rotation as a whole and, in the future, its carbon economy.

**b) Above the soil**

As well as below ground, there are many potentially useful interactions among crop plants and all other organisms that live above and within the soil. To maximise, or better, optimise, the range of useful reactions, it is essential to adopt polycultural rather than monocultural systems (see Table 1). However, this depends on the form of monoculture and the crop in question.

Table 1. Some characteristics and examples of different systems of mono- and polyculture.

| System | Monoculture - single species | | Polyculture - multiple species | |
|---|---|---|---|---|
| Genetic variation | Low | High | Low | High |
| Interaction potential | Minimal | Moderate | Moderate | High |
| Examples | Pure line varieties or clones | Variety mixtures | Sole cropping: rotations, sequential cropping | Row, strip (bed), plot inter-cropping; agroforestry |

Monoculture

Monoculture is defined by a single *species* being grown in the same place year after year. This does not necessarily imply genetic uniformity since different varieties may be grown in different years or the crop may be grown as a variety mixture. The risk to the crop from abiotic or biotic variables is potentially greater if the monoculture is genetically uniform. The potential for interactions with other species of organism is relatively less than in polyculture. It seems likely that the major staple crops used by man, particularly the cereals, evolved in large monocultural stands of single species, but with extensive genetic variation. Such stands would have been incorporated easily into early agriculture to give stable production of relatively high yields. Later, such stands were refined gradually into increasingly pure line varieties, supported by an increasing range of inputs which became essential to maintain them.

Monocultural systems with no genetic variation, convenient for industrialised handling and processing, are difficult or impossible to maintain. An example is the disastrous attempt to produce clonal lines of starch potatoes as large-scale monocultures close to starch factories. Potatoes are mostly grown in polycultural rotations, although these are also difficult and expensive to maintain relative to the genetically variable mixtures grown in the Andes. The concept of variety mixtures (Wolfe, 1985; Garrett and Mundt, 1999; Finckh *et al.*, 2000) provides a way of increasing the genetic variation and interaction potential while maintaining the advantages of monoculture. Examples of effective variety mixtures include all cereals, oilseed rape, coffee, soya bean, other beans, willow, apple, lettuce, potato, swede and turnip (Finckh *et al.*, 2000; Wolfe, 1985; Zhu *et a.,l* 2000).

Interactions among the components can buffer variety mixtures against variable physical environments and affect development of diseases, pests and weeds. Garrett and Mundt (1999) reviewed and summarised the known mechanisms that operate in variety mixtures to restrict disease development. Their analysis included a summary of the types of pathogen that would be most, and least, affected by variety mixtures. The main mechanisms are:
- increased distance between susceptible plants so that fewer spores can spread to their hosts
- non-susceptible plants growing between the susceptibles form a barrier to spore dispersal
- pathogens non-virulent on one variety may induce resistance against otherwise virulent races
- selection for resistant or competitive host genotypes may provide compensation for any plants in the mixture that are infected or otherwise weakened
- interactions among pathogen strains on host plants can lead to increase or decrease in disease.

Particularly for short generation pathogens with horizontal dispersal gradients and small lesions (powdery mildews, some rusts), disease restriction by mixtures can be dramatic, up to 94%, with large positive benefits for crop yield (Finckh *et al.*, 2000; Zhu *et al.*, 2000; Wolfe 2000). But useful benefits can be gained from restriction of many other diseases in numerous crops (Finckh & Wolfe 1998) including both annuals and perennials. Other important aspects are simultaneous restriction of several diseases (Elm Farm Research Centre cereal trials at www.efrc.com) in a single crop, and an increase in the overall level of disease restriction as the area of the mixture crop increases (Zhu *et al.*, 2000).

A general conclusion from a review of the interactions of crop mixtures with insect pests (Andow, 1991) was that specialised, monophagous pests could be significantly restrained by crop mixtures, with less marked reductions for less specialised, polyphagous pests. Different mechanisms may be operating:

- increased distance between susceptible plants may hinder insect spread
- density of visual or olfactory cues for insects is reduced
- potential for the occurrence of natural enemies is enhanced, particularly at initial infestation
- there may be an alteration in host quality (for the pest) through plant-plant interactions.

Common mechanisms of interaction of crop mixtures with weeds (Liebmann, 1995) include:
- increased plant density leading to reduction of bare soil and greater competition for light, water and nutrients
- layering of crop components also increases competition for light, water and nutrients
- diversity of tillage operations may disturb weeds

Allelopathy may also be relevant. Most crop mixtures led to significant reductions in weed infestation relative to sole cropping.

Mixtures and marketability.

A frequent question about the practical use of variety and species mixtures is the marketability of the product. The use of mixtures for small-scale marketing or for local livestock feed rarely presents any problem. Unfortunately, large-scale processors have often taken a restrictive view, preferring only pure varieties for industrial-scale processing. This has imposed a limitation on the uptake of variety mixtures. However, observations show that the variation in quality of the produce from a mixture grown in different fields is likely to be less than that from the components grown as monocultures across those environments (Finckh & Wolfe, 1998; Newton *et al.*, 1998).

More importantly, since quality is a complex character with many components, there is a potential for improvement by mixing varieties that have complementary quality characteristics. For example, Newton *et al.* (1998) found that a particular mixture of winter malting barley varieties gave higher hot water extracts than the components grown alone with no effect on homogeneity. In our own trials, the mixture of Hereward, Malacca and Spark, showed improvements in diseases control, yield, specific weight (common in mixtures and probably due to disease restriction), Hagberg Falling Number and crude protein, relative to the components grown alone (www.efrc.com).

For root crop mixtures, if it is preferred to keep the components separate for processing or marketing, automated separation is possible, using, for example, OCR (optical character recognition systems) which are already used extensively in potato processing.

Polyculture

Many crops chosen by man probably evolved in complex communities, in which the essential genetic variation to buffer each species against environmental variation was available partly from within the species and partly from interactions with other members of the community. Indeed, in natural systems, with few inputs except light, air, water and soil, Reich *et al.*, (2001) found that complex mixtures can be much more productive than the same components grown alone. They suggested that as the number of components increases, there is first, an increase in the range of functions in the mixture, second, greater niche differentiation among the components, thus improving exploitation of the local environment, and third, an increasing potential for complementation among different components. These interactions lead to high productivity and durability over a wide range of environmental variation.

Polycultural systems (Table 1) may be less convenient in some ways than monocultures but offer the potential for large increases in genetic variation and interactions, which can provide for a high degree of sustainability in the cropping system. Inter-cropping systems that maintain separate components offer a major potential for increasing biodiversity to buffer against diseases, pests and weeds, from simple bi-crop systems involving grass and legume species to complex agroforestry systems involving trees, field crops and animals. For example, EFRC's agroforestry options include a novel approach to organic broiler production (www.sheepdrove.com). The basis is a hedge system that incorporates not only shade and cover, but a diversity of ground storey plants that are particularly suitable for chickens. The plants will provide the chickens with opportunities for a diverse diet and self-medication within a sheltered habitat well-suited to these forest birds. The self-medication concept is a major development for animal welfare on the farm (Engel, 2002), opening a new avenue for exploitation of functional biodiversity.

The most complex and durable systems integrate different levels of variety and species mixtures grown in agroforestry systems. For example, we are currently developing strip inter-cropping of vegetables (planted as variety mixtures) with a clover variety mixture to integrate production cropping with fertility-building in the same cropping area. The system is arranged in beds that form a crop rotation within the tree alleys of an agroforestry system. Such systems have many potential advantages including pest confusion, spatial restriction of disease and weed spread, nutrient cycling and long-term habitat for beneficial earthworms and arthropods.

Interactions among inter-crop components can occur at many levels. For example, crop plants that are diseased are likely to be uncompetitive against weeds. On the other hand, in organic crops, weeds may a play a positive role in crop disease in mixtures, because the weeds can act as an extra barrier to spore dispersal, or, if they are infected with their own pathogens, produce spores that may induce resistance within the crop (the majority of diseases that occur on weeds are unlikely to provide a source of inoculum for the crop). In non-organic crops, those weeds that survive herbicide applications are likely to be treated inadvertently with fertiliser and pesticides, which can increase their competitiveness against crop plants.

Many of the field interactions that do occur are related to the signalling systems that operate within and among species of plants, animals and microbes. These are likely to be particularly significant and exploitable within mixed cropping systems (for example, Khan *et al.*, 1997). One example is the production by many plants of methyl salicylate, a volatile form of salicylic acid, which has been shown to be important in the induction of resistance both to diseases and to pests in neighbouring, unattacked plants. Interestingly, and perhaps significantly, the same compound (oil of wintergreen) is a valuable medicament for humans. We believe that this emerging area of ecological understanding could become highly significant in helping to rationalise the choice of components in polycultural systems.

Crucially, the benefits from polycultural systems are not limited to control of diseases, pests and weeds. They can provide buffering against a wide range of other environmental variables. And, in terms of sustainability and food security, the diversity of produce from such systems can help to buffer the producer against unexpected variations in the market place.

**Breeding**

Few of the crop varieties used in organic agriculture have been bred for the purpose or are likely to be entirely suitable. Even fewer are likely to be ideal for use in variety or species mixtures or inter-crops. Consequently, we have started a composite cross population programme in wheat (DEFRA grant AR0914), following the Composite Cross programme for spring barley developed in California (Suneson, 1956). Some 20 outstanding wheat varieties from the last half-century in Europe are being crossed in all possible combinations. Segregating population samples from the F2 generation will be grown at a range of organic and non-organic sites to determine the degree and rate at which the populations adapt to the local environment over several generations. If successful, the material produced could be used either directly or as a genetic resource for further selection and breeding. The genetic variation should allow the populations to be rapidly adaptable in terms of disease, pest and weed restriction and to be buffered against variation in the physical environment. From this approach, we should be able to gauge how far we may be able to go with other crops in quickly generating crop populations that are both adaptable and productive. This development will be part of a Europe-wide initiative to try to improve selection and breeding for organic agriculture. It is being coordinated through ECO-PB, the European Consortium for Organic Plant Breeding.

**Future approaches**

In summary, evidence confirms that exploitation of functional biodiversity can provide effective, durable and sustainable buffering against pest, pathogen and weed problems. To extend and improve this approach and to avoid the problems and costs involved in the use of synthetic pesticides, requires a comprehensive increase in the effective use of diversity in agriculture. This requires support for studies that investigate and compare new and improved procedures for effective deployment of biodiversity in crop production and in different kinds of farming systems. There also needs to be development and better understanding of the "whole ecosystem" concept, which treats production agriculture as one component in a complex and highly interdependent ecosystem encompassing all aspects of nature.

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# Development of a systems approach for the management of late blight (*Phytophthora infestans*) in organic potato production: an update on the EU Blight-MOP project

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## ABSTRACT

The recent tightening of EU restrictions on the use of copper fungicides in organic production systems has increased the potential for devastation by late blight of potato (caused by *Phytophthora infestans*). The EU project, Blight MOP, is an attempt to introduce a 'system approach' to late blight management into organic production: integrating agronomic strategies, resistant varieties, diversification strategies and alternative treatments. An overview of the project is given, along with preliminary results from 2001.

## INTRODUCTION

Since 1882, when Alexis Millardet noticed the impact of copper ions on *Plasmopara viticola* infection of grapes, copper fungicides have been used against downy mildew diseases and potato late blight (caused by *Phytophthora infestans*). Copper fungicides continue to be used in organic agriculture. However, the restricted use of copper under EU legislation looked set to expire at the end of March 2002. The expected ban did not materialise, but there was a further tightening of restrictions to a maximum of 8 kg copper per hectare per year. The use of copper in EU organic production is under continuous review, intensifying the need for increased research efforts to find alternative solutions (European Commission, 2002).

Potato is a major cash crop in many European organic farming businesses. Often the most important problem in organic potato production is late blight, a disease that contributes significantly to the 30-40% lower yields in organic compared to conventional production. Thus late blight, without the buffer of copper fungicides, threatens the economic viability of many organic farming businesses.

The EU project Blight MOP, involving 13 partners from seven countries, aims to develop a 'system approach' for the management of late blight, allowing commercially viable production of organic potato crops without recourse to copper fungicides. This system approach is defined as the integrated use of (i) resistant varieties, (ii) available agronomic control strategies, (iii) appropriate diversification strategies and (iv) alternative treatments. In addition, management strategies will be optimised utilising existing forecasting systems, aiming to maximise synergism between (i), (ii), (iii) and (iv). The quantitative target of the project is to maintain potato yields and quality at levels currently obtained with the use of copper fungicides.

To achieve the overall aim of an integrated system approach, Blight MOP is divided into seven individual project objectives:

1. The assessment of the current socio-economic and management impacts of late blight in EU organic potato production systems.
2. The assessment of variety performance in organic production systems in different EU regions, in the context of local blight populations.
3. The development of within-field diversification strategies to prevent/delay blight epidemics.
4. The optimisation of agronomic strategies for the management of late blight.
5. The development of alternatives to copper fungicides, which comply with organic farming standards.
6. The evaluation of novel application and formulation strategies for copper-free/alternative copper based treatments.
7. The integration and maximisation of the most appropriate component strategies into existing organic production systems, in different regions of the EU.

## OBJECTIVE 1. THE SOCIO-ECONOMIC ENVIRONMENT

Since 1995 European organic agricultural acreage has grown, on average, by approximately 20% per year. Organic arable acreages have not kept pace with this overall trend, but have still achieved growth of approximately 12% per year. Potatoes have an important role in many cropping rotations, accounting for about 10% of EU organic arable acreage. Therefore, despite the threat of blight, potatoes retain the status of one of the most important cash crops in EU organic production. This is in an economic environment of farm gate premiums of between 80% and 200% over conventional prices.

The use of copper is inconsistent across Europe. In Scandinavia and Holland copper treatments are not allowed under member state legislation. Despite this, yields in the Netherlands do not appear to be significantly different from most other EU countries, averaging approximately 25 t/ha in 2000 (Table 1).

There are significant differences in the epidemiology of the disease and in agronomic parameters of potato production between European regions. For example, there are differences in the varieties used and late bight epidemics occur significantly earlier in some countries. For instance, in 2000 late blight outbreaks were, on average, significantly earlier in Switzerland (week 21.0) and France (week 23.0) than most other EU countries surveyed (i.e. week 29.0 in UK). However, despite agronomic, epidemiological and legislative differences, when organic potatoes are grown throughout Europe they suffer significant losses due to late blight.

Table 1. Mean yields from 118 farms surveyed across Europe, data from 2000. *L.S.D.* = 5.65 ($P < 0.05$, 111 d.f.).

| **Country** | **Mean Yield (t/ha) in 2000** |
|---|---|
| Denmark | 25.9 |
| France | 22.7 |
| Germany | 22.9 |
| Netherlands | 25.0 |
| Norway | 16.2 |
| Switzerland | 28.3 |
| United Kingdom | 29.4 |

## OBJECTIVE 2. VARIETY RESISTANCE

The availability of varieties with durable resistance to late blight is considered central to an organic systems approach against late blight. However, the suitability of many resistant varieties for organic production in different regions of the EU is unknown. This is because varieties can perform differently under organic conditions, one reason being differences in the levels and availability of nutrients. In addition, the relative impact of copper fungicides in varieties expressing different levels of resistance is not well known. Therefore, the agronomic and economic suitability of a wide range of varieties for organic potato production in different areas of the EU is being assessed. These assessments are also being placed into the context of race and aggressiveness structure of *P. infestans* populations.

The efficacy of copper fungicide application is dependent on variety resistance. This is illustrated in Figure 1 as a significant interaction between the effects of variety resistance and fungicide application, because Lady Balfour, and unnamed cultivars 874120 and 91P36A restricted late blight to a sufficient level to mask the advantage to be gained from copper application. Also, in these varieties, copper treatment did not increase the yield, quality or storability of crops (data not shown). Therefore varieties bred for higher levels of blight resistance, may be produced without the use of copper fungicides. This is because they are able to delay the development of late blight to a comparable level as when copper fungicides are used. Indeed, the performance of newly available maincrop varieties (i.e. Hungarian Sârpo varieties) or newly bred cultivars is encouraging, as they convincingly outperform the commonly grown local varieties.

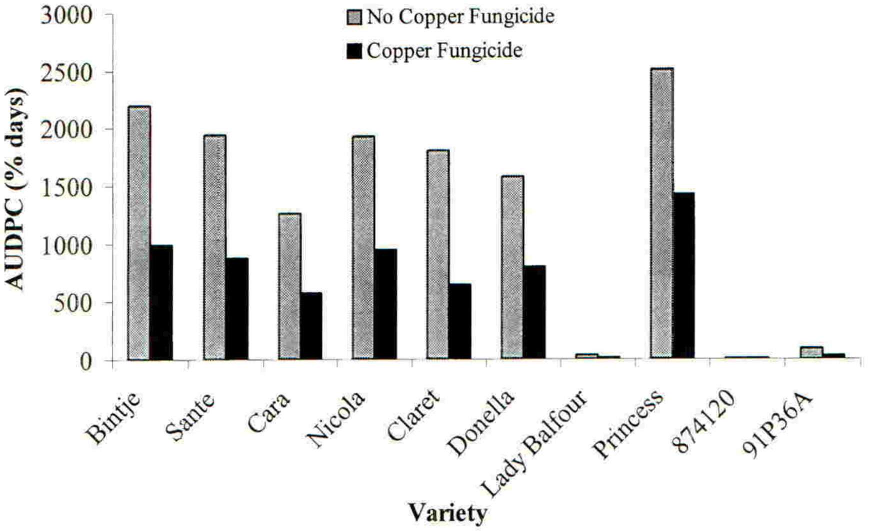


Figure 1. Late blight severity, expressed as the Area Under the Disease Progress Curve, in varieties of potato with and without applications of copper oxychloride (2001 data). The differences between varieties (*L.S.D.* = 233.6, 57 d.f.) and copper treatments (*L.S.D.* = 104.5, 57 d.f.) are significant ($P < 0.001$). There is also a significant interaction between variety and copper treatment ($P < 0.001$). Data provided by the TESCO Centre for Organic Agriculture, Newcastle University.

## OBJECTIVE 3. WITHIN-FIELD DIVERSIFICATION

Diversification, the introduction of functional diversity into cropping systems, reversing the trend to monoculture, has proven an important general principle for crop disease control (Finckh & Wolfe, 1998). Indeed, there is some evidence that blight epidemics can be prevented or at least delayed by growing potato varieties with different forms of resistance as mixtures (Garrett & Mundt, 2000). Another approach is to grow potato in alternating rows with other crops (intercropping), thereby providing a physical barrier for spore dispersal. Field trials aim to quantify the effect of these three different diversification strategies on late blight incidence and progress.

In trials in both Denmark and France, alternating rows of susceptible and resistant varieties did not significantly reduce blight severity in the susceptible varieties. But, a variety demonstrating race-specific resistance showed significant delays in blight when grown alternately with a susceptible variety (Table 2). This is indicative of two main possibilities: (i) an important role for induced resistance where pathogen strain differentiation has occurred, or (ii) a role for alterations in microclimate when the susceptible is defoliated by late blight. Similarly, the usefulness of intimate variety mixtures against late blight is not yet clear (Phillips, 2002). In certain variety combinations the influence of one variety on the other (in terms of disease and/or yield) was significant. A greater understanding of the relative importance of mechanisms in mixtures and alternating rows is required to gauge the potential of these forms of potato variety diversification against late blight.

Table 2. Late blight severity, expressed as Area Under the Disease Progress Curve, for a resistant and a susceptible variety grown in pure stands and in alternating rows. Data provided by the Danish Institute of Agricultural Sciences.

| Treatment | Resistant Pure | Resistant in alternate rows with susceptible | Susceptible Pure | Susceptible in alternate rows with resistant |
|---|---|---|---|---|
| AUDPC (% days) | 1620[a] | 1221[a] | 4390[b] | 4436[b] |

[a] Difference significant ($P < 0.01$, *S.E.D.* = 88.9)
[b] Difference not significant

With species diversification, or intercropping, wheat was more effective at reducing late blight in potatoes in 2001 than either grass/clover or potatoes. However, the competitive effects of wheat reduced yield in adjacent rows of potatoes more than either grass/clover or potatoes. There was evidence that the relative widths of strips of the neighbour crop between potatoes may be critical in achieving the optimum balance of disease reduction in potatoes with the least loss of yield due to competition from the neighbouring crop.

## OBJECTIVE 4. OPTIMISATION OF AGRONOMIC STRATEGIES

Organic farmers routinely adopt agronomic or cultural control methods of preventing late blight. However, there is a need for better-defined optimum agronomic strategies in the context of locality. Therefore, in different regions of Europe, Blight MOP seeks to optimise:

1. Improved removal methods for volunteer potato, a primary source of *P. infestans* inoculum
2. Crop planting dates, seed densities and irrigation schedules; to avoid periods of high blight pressure in the growing season.
3. Nutritional regimes; to avoid susceptibility or increase resistance to late blight
4. Methods and timing of defoliation; to maximise yield while avoiding tuber infection

In principle, advancing potato crop growth by chitting or pre-sprouting seed tubers should result in higher yields being achieved before late blight infects and destroys the foliage. Success of this treatment depends upon variety resistance to blight and environmental conditions (and hence blight pressure), but it may be limited in the absence of copper fungicides. Also, chitting increases physiological age and may increase susceptibility of the foliage and/or tubers to blight. In 2001, a combination of early planting and fully-chitted seed significantly reduced blight, but only for the more resistant variety.

The level of plant population density, in terms of in-row and between-row spacing, affects canopy architecture and structure. This may affect duration of leaf wetness and humidity, both factors that strongly influence *P. infestans* infection (Harrison, 1992). Low population density and wide spacing should reduce humidity and duration of leaf wetness and hence reduce or delay blight infection However, in 2001, there were no significant effects of planting density/configuration on late blight development in foliage or tubers and hence yield. The availability and balance of nutrients affects the resistance of potatoes to late blight. High levels of nitrogen have been shown to decrease plant resistance (Carnegie & Colhoun 1983); while mineral potassium inputs were reported in some studies to increase resistance and in others to decrease the resistance of potato crops (e.g. Awan & Struchtemeyer 1957; Szczotka *et al.,* 1973) However, in 2001 adjusting the levels of nitrogen and potassium, in both field and pot trials, had no effect on blight development (Table 3), but a significant effect on yield (data not shown).

Table 3. Late blight severity, expressed as Area Under the Disease Progress Curve, for two varieties at different nutrient levels. The difference between varieties is significant ($P < 0.001$, $S.E.D. = 11.8$), but no other differences are significant. Data provided by the TESCO Centre for Organic Agriculture, Newcastle University.

| | Nitrogen | | Potassium | | |
|---|---|---|---|---|---|
| | 85 t/ha | 170 t/ha | 50 t/ha | 160 t/ha | 340 t/ha |
| AUDPC (% days) Variety Sante | 673.7 | 652.3 | 652.2 | 676.7 | 654.7 |
| AUDPC (% days) Variety Nicola | 806.6 | 808.7 | 814.2 | 812.4 | 799.6 |

The impact of nutrient status is also dependant on variety maturity type and environmental influences. These influences are being revealed through studies of the effects of rotational position (subsequent to fertility building grass/clover crops or wheat) on potato late blight and crop yield. The nitrogen mineralisation dynamics in the soil under potatoes differed greatly for the two rotations. More work is required to understand the impacts of mineralisation dynamics on late blight and yield but early indications are that lower levels of mineralised nitrogen can be compensated for by the length and quality of growing season. Hence, the agronomic effects of nutritional regime, on both late blight and yield, are a result of complex interactions between plant genotype, environment and soil quality.

Defoliation treatments including flailing, heating treatment and a combination of these two, significantly decrease the number of sporangia produced per plant. However, the type of treatment did not significantly affect tuber blight, but this may not be the case under different weather conditions. Therefore, there is a continuing need to optimise the defoliation strategy and timing for organic production under different weather conditions and where copper fungicides are not used.

## OBJECTIVES 5 AND 6. ALTERNATIVE TREAMENTS AND APPLICATION TECHNOLOGY

Various alternative treatments have been developed for the control of fungal pathogens including microbial antagonists and also plant extracts or compost extracts (Weltzien 1998).

Alternative treatments have direct antifungal effects or stimulate competitor microbes; such treatments can also have effects on the plant through resistance induction. However, there are few reports of successful alternative control approaches using these treatments against late blight and few methods have been evaluated in field trials.

The screening stage of plant extracts and microbial antagonists (biological control products) in the Blight MOP project has been completed and the results are encouraging. Several of the antagonists and extracts showed significant activity against late blight in vitro and bioassay trials. The next stages of this work is to identify the mode of action of the biological control agents and then to determine compatibility between agents, as mixtures often have more reliable effects because a range of mechanisms (e.g. competition for phyllosphere nutrients, induction of resistance and hyperparasitism) may be involved. Antagonists that have antibiotic production as their main mode of action will be identified and these will not be further developed, since this mode of action is prone to resistance development and may not be acceptable under organic farming standards in the future (Li & Leifert 1994). Many microbial antagonists and plant extracts show optimum biocontrol activity at specific concentrations and environmental conditions (e.g. Berger *et al.* 1996). Moreover, the persistence/longevity of active compounds on leaves varies considerably. Hence, the final stage of the alternative treatment work is to examine application rates and frequencies giving maximum control of blight.

## OBJECTIVE 7. INTEGRATION OF SYSTEMS APPROACH

The relative effect of component strategies and the most effective combination of individual component strategies (resistance management, diversification, agronomic methods and alternative treatments) will depend on local conditions. For example, improved volunteer control strategies of all farms in a region may be essential for regions with maritime climates which have a low incidence of ground frost, but may have no impact in regions of continental Europe where strong ground frosts kill most tubers left in the ground.

Regional and site-specific environmental conditions (climate and soil type, fertility and water availability; inoculum sources; microclimatic conditions) will influence the initiation and subsequent spread and dispersal of late blight. Key environmental and soil parameters are therefore being characterised in most field trials. Environmental parameters (in particular air temperature and relative humidity) have been used to develop algorithms, which quantify "blight pressure", and to identify dates when blight treatments should commence. Using this information, we therefore hope to be able to:

1. Utilise existing mathematical models to analyse the efficacy of component strategies in the context of local "blight pressure indices".
2. Quantify & rank (in order of impact for different EU-regions) individual component strategies.
3. Design regionally adapted blight management systems based on the base line data from the survey carried out under objective 1 and the experimental data from the other objectives.

Hence, the most important aspect of Blight MOP is considered the integration of all novel blight strategies into model farming systems. This demonstration will also act to validate the efficacy of the regionally adapted blight management systems under field trial situations and provide a valuable means of dissemination.

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# Developing improved strategies for pest and disease management in organic vegetable production systems in the UK

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## ABSTRACT

Organic pest and disease management strategies should, from principle, be largely preventative and depend on a whole systems approach, with maintenance of soil health a central component of any strategy. This paper presents a summary of the most serious pest and disease problems encountered in a range of organic vegetable production systems over the past three seasons in England and Wales. The major crops all showed some specific pest and disease problems and overall about 10% crops had serious losses. Growers consistently rated potato late blight as the most important disease problem and carrot fly, aphids and cabbage root fly as important pests. Slugs and birds are also a significant, but probably underrated problem, in crops such as brassicas. Priorities for improving management strategies can now be identified. Knowledge transfer is a key issue, as growers require a high level of biological understanding to plan and manage organic systems. Various factors, such as size and type of enterprise, past cropping practices, the economic and biological diversity of the holding as well as the marketing outlets of the farm, are likely to affect the type and effectiveness of management strategies employed.

## INTRODUCTION

Pests and diseases are often perceived by conventional growers as being a major constraint to converting to organic production methods, whilst established organic growers often rate them as of less importance (Alteiri, 1984) in relation to other production factors such as maintenance of soil fertility. In fact, the proportion of organic crops lost to pests and diseases is often smaller in organic than in conventional systems (Plumb, 2000), which is partially explained by the lower yields of organic crops and due to other factors such as the low N status of the crop reducing susceptibility to diseases and pests. Recently, however, Litterick *et al.*, (2002) have judged that the lack of practical, cost effective crop protection strategies is one of the key factors limiting expansion of UK organic agriculture.

Organic growers (and researchers) have traditionally perceived crop pests and diseases as problems within a farm system rather than isolated problems. In consequence, organic crop protection requires specific management skills and knowledge as growers generally try to manipulate the crop environment and the crop plant (including use of resistant cultivars) to suppress pests and diseases, rather than rely on direct intervention or curative treatments. Where treatments are necessary they should only be used as a last resort using substances permitted under organic standards (meeting EU regulation 2092/91).

The area in conversion to, or under organic production, in the UK has been increasing rapidly. In 1999 2930 ha of organic vegetables were grown in the UK. By 2000 this had increased by 44% to 4205 ha, of which 49% was potatoes (Soil Association, 2001) Before this increase, organic vegetables were mainly marketed more or less directly through farm or local retail shops and box schemes. More recently, supermarkets have begun to play a much larger role in marketing organic vegetables. This change in marketing pattern has had a direct influence on production practices especially as regards increased demands for uniformity of appearance, packaging of produce and maintaining continuity of supply. This, in turn, has influenced the type and scale of enterprise that is likely to become involved in organic production, as larger, more specialised, producers are able to accommodate the increased production costs that increased specifications demand. Smaller producers are still more likely to rely on selling more directly through box schemes or, increasingly, farmers markets. However, some larger producers are also becoming interested in direct marketing schemes.

All these changes are likely to influence the perception of pests and diseases among organic growers, even among those smaller producers, whom, although selling into more flexible direct markets, are still, at least to some extent, competing with supermarkets. Pest and disease management programmes might also be expected to become more risk averse, and hence, direct or curative as production costs increase. Langer (1995) has reported on pests and diseases of organically grown vegetables in Denmark and considered that perceptions of damage and loss changed with marketing patterns and quality demands although, at that time, cultural methods such as timing of sowing and rotation predominated over direct control methods. As the availability of organic vegetables in the UK has increased, both from home production and imports, the specifications have become tighter and many growers report that there is now no difference between organic and conventional specifications. When the market is over-supplied for certain crops, zero tolerance of damage can apply.

## OBSERVATIONS ON PEST AND DISEASES IN ORGANIC VEGETABLE SYSTEMS

In the present study we have summarised data from three principle sources to take a snapshot of pest and disease problems in organic vegetable production systems over three seasons (1999-2001). Direct observations on pests and diseases were obtained from survey work on fourteen farms representing a range of farming systems (intensive stockless vegetables, arable/vegetable and mixed farming) using standard pest and disease survey techniques. Farms were usually visited three or more times during the vegetable growing season. All observations were entered on a database and were classified as to damage caused (either yield or quality reduction) from slight (no damage), moderate (some damage) to severe (considerable damage). The database was used to generate reports divided by enterprise field size (large (>2.5 ha) versus small (<2.5 ha), which represents to some extent farm philosophy and marketing strategy) and by the number of seasons in which the problem was observed. Table 1 shows pests, and Table 2 diseases, which were classified as moderate or severe over the survey period

Table 1: Key pests observed in organic field vegetables, 1999-2001.

| | | Farm System | | Grower | |
|---|---|---|---|---|---|
| Crop | Disease/Pest | small | large | priority | Causes of problem identified by growers |
| Carrots | carrot fly | - | * | ••• | market specs, products, knowledge transfer |
| | slugs | - | - | ••• | rotation, knowledge, cost of control |
| | vertebrates | - | - | •• | high cost of control measures |
| | nematodes | - | - | •• | rotation issues |
| Brassicas | aphids | * | *** | • | |
| | vertebrate | * | ** | ••• | cost control measures, poor knowledge transfer |
| | slugs | - | * | ••• | rotation knowledge, products, knowledge transfer |
| | cabbage root fly | * | *** | •• | cost control measures, knowledge trans |
| | caterpillar | - | *** | ••• | market specifications, knowledge trans |
| | flea/pollen beetles | | | ••• | lack of knowledge, technologies |
| Leek | thrips | - | ** | - | market specifications |
| Lettuce | aphids | - | * | ••• | large field size, no predators, no aphicides |
| | vertebrate | - | ** | • | high cost of control measures |
| | leatherjackets | - | * | • | rotation (leys) |
| | slugs | - | * | • | rotation, knowledge, cost of control |
| | cutworms | - | - | • | rotation (leys) |

problem observed * problem in one season ** problem in two seasons *problem in 3 or more seasons
grower priority • low •• medium ••• high

supplemented by observations made by growers at open days and workshops during the same three-year period. These included answers to informal questionnaires at three open days (76 replies) and open workshop sessions on pest and disease problems in lettuce, brassicas and carrots held in 2001-2002 (available at CABI, 2001). This information has been used to assign grower priorities to pests and diseases depending on the number of growers reporting the problems or grower prioritisation at workshops. This is reported together with some indication of growers opinions as to the causes of the problems (Table 1 and Table 2).

Both pests and diseases were found to be common in organic vegetables and some caused moderate or severe losses. Pests in particular were more often observed as problems in 'large enterprise' farm systems. Overall serious losses from diseases were found in 10% crops. In total, 61% of all observations were made on large farms, which accounted for 71% of the moderate or severe problems. This imbalance was accentuated in specific crops; 35% of observations on potatoes were made on large farms and these accounted for 64% of the moderate or severe problems encountered. Similarly, 64% of observations on brassicas were made on large farms accounting for 75% of the severe or moderate pest and disease problems.

Pest problems predominated in brassica, carrot and lettuce production systems, where key pests included; slugs (various species), birds (especially pigeons (*Columba palumbus*) and rooks (*Corvus frugilegus*)), caterpillars (*Pieris* spp. and *Plutella xylostella*), cabbage root fly (*Delia radicum*) and aphids (*Brevicoryne brassicae*) in brassicas, carrot fly (*Psila rosae*) in carrots, slugs (various species) in potatoes, and slugs (various species) and aphids (*Nasonovia ribisnigri* and *Pemphigus bursarius*) in lettuce.

Table 2: Key diseases observed in organic field vegetables, 1999-2001.

| | | Farm System | | Grower | |
|---|---|---|---|---|---|
| Crop | Disease | small | large | priority | Causes of problem identified by growers |
| Carrots | cavity spot | * | * | ••• | knowledge transfer, varietal resistance |
| | violet root rot | * | - | •• | knowledge transfer, varietal resistance |
| | leaf blight | | ** | ••• | knowledge transfer, varietal resistance, infected seed |
| Celery | leaf spot | * | *** | •• | infected seed, market conditions |
| Brassicas | clubroot | - | ** | • | |
| | dark leaf spot | * | *** | • | varietal resistance, product standards, knowledge |
| | downy mildew | - | * | •• | varietal resistance, product standards, knowledge |
| | ring spot | - | *? | • | varietal resistance, product standards, knowledge |
| | white blister | ** | ** | • | varietal resistance, product standards, knowledge |
| Leek | rust | * | *** | ••• | |
| | white tip | - | - | • | rotation |
| Lettuce | downy mildew | ** | *** | ••• | late production, weeds |
| | head rots | * | ** | •• | planting methods |
| | virus | - | - | • | aphid control, seed? |
| Onion | downy mildew | * | *** | ••• | |
| | white rot | * | - | •• | need extensive rotation |
| | neck rot | * | * | •• | Infected seed, harvest and storage conditions |
| Parsnip | canker | - | - | • | |
| Potato | potato blight | *** | *** | ••• | external epidemics |
| | common scab | - | * | •• | very high market specifications |
| | blackleg | * | * | • | market specifications |
| | black scurf | | * | • | market specifications |
| Pumpkin | grey mould | * | - | • | |
| /cucurbits | powdery mildew | ** | ** | •• | |

no problem observed * problem in one season ** problem in two seasons *problem in 3 or more seasons
grower priority • low •• medium ••• high

Moderate to severe disease problems were encountered across a wider range of vegetable crops than pest problems. Key diseases included; potato late blight (*Phytophthora infestans*) and skin finish diseases (e.g. common scab (*Streptomyces scabies*) and black scurf (*Rhizoctonia solani*)) on potatoes, leek rust (*Puccinia allii*), onion downy mildew (*Peronospora destructor*) and neck rot (*Botrytis allii*) on alliums, clubroot (*Plasmodiophora brassicae*) on brassicas in specific locations as well as some of the brassica foliar diseases where they directly affected the marketable parts of the plant (e.g. dark leaf spot (*Alternaria brasicae, A. brassicicola*) and white blister (*Albugo candida*) on brussels sprouts), downy mildew (*Bremia lactucae*) and head rots (e.g. *Botrytis cinerea*, *Sclerotinia* spp.) in lettuce, and celery leaf spot (*Septoria apiicola*).

Crop surveys have probably underestimated the extent of problems because crops maturing in late autumn or winter and stored crops were not examined. However, the results are in broad agreement with those of Langer (1995) and Peacock (1990), although they identified fewer problems for organic growers; namely slugs, birds, carrot fly, cabbage root fly, potato late blight and onion neck rot. Baker & Smith (1986) put this in context by the noting that weeds, marketing, machinery and drought were often considered to be more serious problems by organic growers than pests and diseases.

## PEST AND DISEASE MANAGEMENT STRATEGIES

Organic pest and disease management strategies should involve careful pre-cropping planning to minimise risks of problems. Growers are using the components identified by Peacock (1990) including: 1) avoiding problems (by not growing the crop, avoiding hot spots), 2) isolating crops, 3) producing 'healthy' plants, 4) using preventative (cultural) methods (such as cultivations, rotations, transplanting, destruction), 5) using resistant varieties, and 6) occasionally using curative methods (such as BT, copper fungicides or plant extracts). In the final resort, most growers also accepted damage to some extent. At this time lack of knowledge of pest and disease life histories on the part of growers was seen as major problem, with growers using a series of complex labour intensive, largely ineffective, and (hence) expensive crop protection methods.

Our experience indicates that many pest and disease management choices for organic growers are in fact constrained by other factors as shown by the causes given for pest or disease problems by growers (Tables 1 and 2). Crop or varietal choice is often largely dictated by market, especially when selling through large multiple outlets. Flexibility to manipulate cultural practices such as sowing times are in practice constrained by schedules where continuity of supply is an important consideration. In addition, growers frequently cite inadequate knowledge of pests and diseases as the root of problems, which indicates a possible problem with current technology transfer programmes.

Whilst growers might be more or less constrained in their choice of management options many resort to the use of more direct or 'interventionist' control measures, including defoliation, crop covers and permitted amendments or biocides. Some pest control techniques are widely used in specific cases, e.g. Bt against caterpillar pests in brassicas, crop covers in carrots against carrot fly, and defoliation and copper in potatoes against late blight. Many of the observations on the use of direct control measures were made on recently converted organic farms (10 farms) where these farmers are having to adapt their strategies from conventional approaches. Initially they may look for an organic equivalent to a conventional product and may lack confidence to rely on natural systems such as predator populations. This is especially so in the context of the high risk of losses due to crops not meeting market quality specifications.

## DISCUSSION

The implications of the survey results indicate that although a wide range of pests and diseases are found in organic vegetables there are a few key pests and diseases in each crop, which are causing serious losses in about 10% of crops. These problems are targets for improved management strategies. Our data suggest that there are potentially greater pest and disease problems on larger organic units and these face a significant challenge in adapting their current farming systems.

Monitoring of organic farms suggests that strategies are not fully exploiting available options and some growers are persisting with approaches that are giving repeated losses. Improved strategies will need to be matched to specific problems. For example, improvements in seed health would overcome problems with *Alternaria* leaf blight in carrots and leaf spot in celery. Better exploitation of cultivar resistance and increased use of diversity at species and cultivar levels should improve management of foliar diseases in many crops, lettuce downy mildew being a key target. Where continuity of cropping is required, successive plantings should be isolated from each other so that spread of pests and diseases between crops is reduced. Where soil-borne pests and diseases occur, longer rotations and avoiding susceptible crops would beneficial. Soil tests for pests and diseases and within season forecasting systems offer further guidance on potential risks. In the longer term, further development of pest and disease control strategies will be required. Organic seed treatments, alternatives to copper fungicides and biological control agents for disease control would be useful, but fundamental understanding of soil microbiology and pest and disease dynamics is also required to develop sustainable organic systems. Growers have identified knowledge transfer as an area for improvement and participative research projects are now in progress to assist this process. However, the results also emphasise the importance of monitoring any changes over time, which in turn will allow the identification of periods of risk and/or risk factors which, will in turn, allow the development of better pest and disease management strategies for organic growers. Such developments should allow better and targeted use of the more direct control measures already being taken by organic growers and their possible substitution by longer term strategies to manage pests and diseases.


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