RESEARCH TOPIC REVIEW:
Controlling pests and diseases in organic field vegetables

Authors: Anton Rosenfeld and Phil Sumption

1. Scope and Objectives of the Research Topic Review:

This review aims to provide a summary and analysis of the most recent work carried out on pest and disease control measures relevant to organic systems. It focuses primarily on organic field vegetables. An organic approach to controlling pests and diseases does not merely replace conventional pesticides with biological alternatives. A whole systems approach is employed in order to build a system whereby pests and diseases are less likely to occur in the first place. It is also acknowledged that organic systems place emphasis on balance. It is well known that a non selective insecticide can eliminate the predators as well as the pests, leading to a worse problem than at the start. In organic systems, low levels of pests and diseases are frequently present, and these are usually tolerated as they do little economic damage to the crop. What is considered economic damage is somewhat dependent on the market for which the crop is destined. One or two currant lettuce aphids on a little gem lettuce may be perfectly acceptable for a local market or box scheme but not for a supermarket packer. The extremely low levels of pest and disease damage often demanded by supermarket packers can be difficult to reconcile with organic systems, as it requires a high degree of direct intervention methods.

This article reviews a range of topics in order to address some key problems within the vegetable growing industry. This review covers both work that can be readily adopted in commercial practice and work that requires further research before it is ready to be taken up.
The topics and scope of the review are listed below:

1. Management and rotations to prevent pests and diseases
How can systems and cultural measures be employed to control diseases?
What forecasting systems are available and how can they be used to help control diseases?
What seed treatments are available to prevent diseases being introduced into the field?

2. Varieties suitable for use in organic systems
What varietal programmes are currently taking place to select varieties with good resistance to pest and diseases?
How can Sárpo varieties of potatoes be used against late blight?
How can plant breeding techniques help control diseases in organic systems?

3. Products being developed for organic systems
What fungicides are being developed for use in organic systems?
Are new biological insecticides being developed?

4. Biological control measures
Can compost be used to suppress soil borne diseases?
What is the potential for entomopathogenic fungi as a means of controlling pests?
Can biofumigants be used to control soil borne diseases?

5. Other strategies
How can predator numbers be boosted in crops?

Can distraction techniques such as companion planting or strip cropping reduce pest infestation?
Can planting arrangement reduce disease?

6. Potential for new products
What new products are available to organic growers?

2. Summary of Research Projects and the Results

2.1 Management and rotations to prevent pests and diseases

How can systems and cultural measures be employed to control diseases?

A systems approach is key to reducing the incidence of pests and diseases in organic systems. This section reviews such an approach that is employed to control late blight (*Phytophthora infestans*) in potato.
Late blight still remains a major cause of crop loss in organic potato production. A number of projects (Tam et al, 2004; Zarb et al, 2002) have identified the key cultural measures for controlling the disease, and most of these strategies are well known amongst growers. These include:

a) avoiding periods of high blight pressure (e.g. chitting of seed)
b) avoiding excessive crop nutrient supply (especially of nitrogen)
c) reducing periods of leaf wetness/high humidity in the stand
d) preventing incidence of primary inoculum sources
e) preventing tuber blight (e.g. by early foliage removal).

The Blight Mop Project (Tam et al, 2004) performed a detailed survey of seven European countries. The aims were to
1. Obtain an inventory of the current organic potato production techniques,
2. Assess the impact of a potential ban of copper on yields and viability of organic potato production
3. Identify alternative plant protection strategies that are used by organic farmers.

The project highlighted the following findings:

- Organic and conventional farmers do not grow the same choice of varieties. The varieties grown by organic farmers tend to be a compromise between robustness in production and acceptance on the market.
- There are legislative differences in the countries included in the study, which have an influence on production conditions. Consequently copper applications between countries varied between 2 kg/ha to 16 kg/ha. In the Netherlands and Scandinavia, copper cannot be used at all.
- Other preparations were tried including algae, biodynamic preparations, microorganisms or extracts thereof, rock powders, plant extracts, soaps of fatty acids, and milk extracts, plus a variety of plant strengtheners with unspecified mode of action but these were generally found to be ineffective.
- The study showed that growers used widespread cultural control measures against the disease. Of these, use of less susceptible varieties was the most effective.
- Early planting date, early harvest date and timely removal of foliage were also important for controlling the disease.

- Other strategies such as intercropping were of little benefit, and changing agronomic practices such as plant spacing had no effect on the disease at all.
- Use of manure preparations was successful in controlling blight in leaf assays but was not effective in the field.
- The study concluded that copper is still used extensively, and that a ban in the absence of adequate alternative production strategies would most likely lead to destabilisation of organic potato production, decrease in production area and shortage of market supply.

What forecasting systems are available and how can they be used to help control diseases?

Forecasting systems can play an important role in organic pest and disease control. They usually require the input of climatic data into a model which then predicts the level of pest infestation or disease infection. Although many of the models were initially designed to optimise the timing of spraying with pesticide, many are equally applicable to organic systems. They can be used to predict when the most severe outbreaks are likely to occur and the timing of cultural measures, planting and harvesting adjusted accordingly. Another approach is use a network of recording stations, which is then made publicly available to provide an early warning system.
In order to formulate models, a good understanding of the biology and life cycles of host pests is required. Such knowledge is not only used in the development of models but provides useful information for strategic control of the host pest. A recent example of research work was carried out by the HDC (2007) to further elucidate the biology of the currant lettuce aphid (*Nasanovia ribisnigri*). This is an important pest of lettuce crop and can lead to widespread economic loss, especially in organic crops, where control measures are limited. It infests lettuce crops in early summer, where populations increase rapidly for several weeks before showing a rapid crash. The reasons for this mid season crash are still not understood in this species or other species of aphid such as cabbage aphid. Following the crash, the pest re-establishes and numbers increase in September and October when they become the dominant pest on the crop. They then migrate as a winged form to blackcurrant, redcurrant or gooseberry bushes, give rise to wingless females that then mate and lay eggs, remaining in dipause over the winter.

This project served to clarify key points over the life cycle of this pest which are summarised below:

- The aphid could complete its life cycle from nymph to adult in 8 days at a temperature of 20°C.
- Late season population of aphids was increased if the lettuce crop was covered. This could be for a number of reasons. It may have excluded predators from the crop.
- The migration of the lettuce currant aphid plant from lettuces to currant bushes occurred in October and November. The dates of migration recorded agreed well with others recorded in the literature and this migration is thought to be triggered by shortening day lengths in autumn.
- Under mild winters, aphids could overwinter on alternative host species of plants such as chicory or speedwell. If temperatures are high enough, females remained and active and could continue to produce nymphs rather than laying eggs.

Such knowledge on insect behaviour and life cycles can be fed into predictive models. One such model developed (HDC, 2001) uses climatic data to predict the populations of three key species of aphid on lettuce crops: the currant lettuce aphid (*Nasanovia ribisnigri*), potato aphid (*Macrospihum euphorbia*) and peach potato aphid (*Myzus persicae*). The research to develop these models outlined the following findings:

- All three species reach a peak in mid summer before showing a crash in the population. The currant lettuce aphid then attains a second peak in the population in September.
- Potato aphid and peach potato aphid populations increase earlier following a mild winter, whereas current lettuce aphid population dynamics are not related to winter temperature but related to spring temperatures.
- Site location also affects the timing of colonisation. There is a tendency for aphids to fly earlier, and in greater numbers, further south and east.
- Real time information on captures of peach-potato and potato aphids in suction traps may also provide useful information to growers, even though the closest suction trap is 50 miles away from their farm.
- Suction trap captures are unlikely to provide useful information to growers about the currant-lettuce aphid because, in general, very low numbers are captured in suction traps.
- Peak numbers of all three species of aphid occur usually at the same time.
- As yet we do not understand the cause of the mid season population crash. It may be due to natural enemies, including entomopathogenic fungi. It is unlikely to be caused by the changing physiological state of the host crop, as the crash occurs at the same time in sequentially planted plots of lettuce.
- None of the forecasts are likely to be accurate to within a week and may only be accurate to within a few weeks. This is due to the considerable variability in the data on which they are based.

Similar, temperature based models have been used for predicting the timing of outbreaks for cabbage root fly (*Delia radicum*) and carrot fly (*Psila rosae*) (HDC, 1999a):

- The forecasts indicate timing of pest attack, so that growers can target appropriate cultural control measures. They cannot predict the severity of infestation as this depends on the size of the local fly population.
- The forecasts for most areas coincide almost exactly with the activity of the flies in the field since they generally estimate the times of 10% and 50% fly activity to within one week of observed activity in most regions of the country.
- The only data that needs to be put into the model are air temperature and soil temperature on a daily basis.

This model information along with recorded information from 13 trap sites is available to HDC members to provide a useful tool throughout the growing season.

A number of models have also been developed for predicting disease epidemics at Warwick HRI, funded by Defra and HDC including the Brassica$_{spot}$ model and the Onion$_{spot}$ model. The former of these predicts the diseases ringspot (*Mycosphaerella brassicicola*) and dark leaf spot in brassicas (*Alternaria brassicae*) whilst the latter predicts the progress of *Botrytis squamosa* in onions. (see HDC, 2000).

Information on potato blight outbreaks is also available to potato growers through the British Potato Council website (www.potato.org.uk/blight). As with the aphid monitoring, there is a system of scouts that report when blight infection occur within a locality. This is an important tool for growers, as source of inoculum is an important factor determining blight outbreaks in organic potato crops. There is also a system alerting growers to the occurrence of Smith Periods. A Smith Period is said to have occurred if on each of 2 consecutive days:

- The minimum air temperature was at least 10°C, and
- There were a minimum of 11 hours with a relative humidity of at least 90%.

Under these conditions, the blight pathogen has a much greater chance of sporulating and growers should be aware that disease outbreaks are more likely to occur.

What seed treatments are available to prevent diseases being introduced into the field?

The EU-funded STOVE project - *Seed Treatments for Organic Vegetable Production* evaluated non-chemical methods for control of seed-borne pathogens in organic vegetable production (Amein et al., 2006). Physical methods (hot air, hot water and electron) and biological methods (microorganisms and different agents of natural origin) were investigated. Trials were carried out on pathogens of different crops such as *Alternaria* spp. on cabbage and *Septoria petroselini* on parsley. Key findings from the project are listed below:

- Good control was generally obtained with the physical methods. In field trials, the yield of parsley naturally infested by *S. petroselini* was increased by 20 % when the seeds were treated with hot air.
- In trials performed under controlled conditions thyme oil treatment also increased the number of germinated seedlings of this crop compared to the untreated control.
- Treatments with different commercialised microbial preparations reduced incidence of disease caused by *Alternaria spp*. in cabbage seedlings to a level similar to that achieved after chemical treatment.
- Many of the non-commercialised micro-organisms also clearly reduced disease incidence.

2.2 Varieties suitable for use in organic systems

What varietal programmes are currently taking place to select varieties with good resistance to pest and diseases?

NIAB and HDRA conducted organic vegetable variety trials, funded by MAFF and latterly Defra from 1990 until 2007 (NIAB, 2001; NIAB, 2004; and NIAB, 2007). The trials covered 22 vegetable and salad crops and hundreds of varieties. Each year approximately 15 varieties were tested for 6-7 different vegetable crops (including potatoes) on two organic sites for each crop. The varieties evaluated were ones that the industry (seed companies, growers etc.) thought had potential organically, ones available as organic seed, or soon to be available as organic seed. The results were collated in booklets, published biennially. The last Organic Vegetable Handbook (NIAB, 2007) listed nearly 500 varieties that were currently available. The results were also disseminated through annual open days, held at Ryton Organic Gardens near Coventry, to NIAB members and through the Centre for Organic Seed Information (COSI) website, which was funded by Defra. The project funded NIAB and the Soil Association in setting up a comprehensive organic seed information database and communication network, including the collection of both organic and conventional performance data for the varieties listed as available as organic seed. In the last organic vegetable variety trialling project funded by Defra (NIAB, 2007) an element of participation was included with 5 grower groups hosting trials. In 2005 each group hosted trials of lettuce and cabbage and in 2006 potatoes and leeks. The idea of the participative trials was to compliment the data from the more formal replicated trials. In all the trials performance against pests and diseases was very important with varieties scored for pest and disease resistance on 1-9 scale, where 9= high resistance.

How can Sárpo varieties of potatoes be used against late blight?

Hungarian Sárpo potato varieties have shown a high degree of resistance to potato late blight (*Phytophthora infestans)*. The commercially available and nearly available varieties Axona, Mira and Kifli have been evaluated as part of the NIAB variety trials (NIAB, 2007). Axona demonstrated excellent foliage blight resistance even under inoculated trial conditions in both 2005 (NIAB, 2005) and 2006 (NIAB, 2006). Independent field trials have also been carried out by ADAS Wales (Anon, 2005) of 19 Sárpo cultivars provided by the Sárvári Research Trust to examine the level of resistance to late blight in Sárpo potato cultivars compared to commercially available cultivars in a high risk blight area. Other agronomic characteristics including yield vigour and growth of Sárpo cultivars under organic husbandry were also assessed. The conclusions of the trial were:

- Each Sárpo cultivar showed high blight resistance.
- Blight resistance in Sárpo cultivars was greater than in commercially available cultivars in the trial.
- There was a considerable range in yield between cultivars.
- Yield differences for commercial cultivars was associated with susceptibility to foliar blight. Yield differences in Sárpo cultivars was associated with vigour/weed competition rather than susceptibility to foliar blight

How can plant breeding techniques help control diseases in organic systems?

Defra-funded project *Variability in Fungal Pathogens* (HH0916SFV) (Defra, 2003a) looked at disease resistance as a trait to include in plant breeding programmes. The project looked at brassicas and in particular *Peronospora parasitica* and *Albugo candida* which cause downy mildew and white blister respectively. Isolates were collected from vegetable brassicas and two weedy wild relatives shepherds purse and thale cress. Sources of resistance in doubled-haploid lines, along with methods and corresponding isolates, were found and are available for use by industry for conventional breeding.

Objectives were:

1. To produce a set of host differentials for use in studying pathogen variability.
2. To establish a collection of UK isolates.
3. To characterise the isolate collections for virulence phenotype.
4. To determine the allelic relationship between different resistance factors.
5. To classify pathogen isolates into subspecifc groups by comparing variation in ITS sequences.

The project advanced the knowledge of disease resistance in Brassica oleracea. The following key findings from the project were:

- Downy mildew resistance, is conferred by a single dominant R gene and is potentially vulnerable if deployed alone. A second identified source of downy mildew resistance should also be used in UK brassicas, together with the previous R-gene.
- Four sources of white rust resistance were revealed. One of these was observed in three lines and provided broad spectrum resistance to all of the isolates.
- Intermediate white rust resistance was also observed in lines that were derived from popular (unselected) cultivars. Although this resistance was only effective against a small proportion of isolates, it indicates that useful resistance can be unintentionally lost in a breeding programme.

- It also suggests that the existing cultivars of several crops types are in general more vulnerable to downy mildew, because many will already provide some level of protection against white rust. Given the differences in control possible with each of the four sources of white rust resistance, they should all be developed in parallel for eventual deployment in vegetable brassicas.
- Work comparing isolates of *Peronospora parasitica* in brassica crops and *Capsella bursa pastoris* (Shepherds Purse) suggested that Capsella (a common weed in vegetable brassicas) is not currently a common host for pathogen variants that will pose a threat to vegetable production in the UK.

Defra have funded a Plant breeding and variety selection for organic cropping project - OF0375 (Defra, 2009), which started in 2007 and is led by Warwick HRI. This project aims to promote breeders' involvement in reducing agriculture and horticulture's environmental footprint by breeding varieties suited to lower input production systems. To do this it is necessary to:

1) define quantifiable targets;
2) create appropriate market signals/incentives;
3) align variety testing systems with this.

A desk study was carried out to identify variety characters that could lead to the development of more sustainable low input systems for horticultural crops and propose test methods for the assessment of these characters and how the results from the tests might be analysed and reported in a meaningful way for decision-making purposes (Sumption, 2008). Through another desk study and a case study of a small 'regional' breeding company, the constraints imposed by the current National Listing trialling system on the development of vegetable varieties for sustainable production and/or 'regional' varieties were ascertained. Pilot trials were then done in 2008/2009 to determine the practicality of assessing 'traits for low input production' in a trialling system.

2.3. Products being developed for organic systems

What fungicides are being developed for use in organic systems?

In the Development of disease control strategies for organically grown field vegetables project (DOVE) potential organic treatments identified from the literature review were evaluated against specific foliar and soil-borne pathogens in glasshouse experiments to identify their efficacy and spectrum of activity (Defra, 2002a). Note none of these have been passed through the UK Pesticide and Safety Directorate so could not be sold commercially as a pesticide. Potential conditioners or biocides were evaluated against downy mildew (Bremia lactucae) and grey mould (Botrytis cinerea) on lettuce cv. Saladin and against dark leaf spot (Alternaria brassicae) on chinese cabbage. Novel treatments included; rapeseed oil, garlic oil, neem oil, salicylic acid (Aspirin), milk 50 % v/v, dock root extract, seaweed extract and comfrey extract. Findings from the project were:

- All treatments gave significant reductions in the severity of dark leaf spot and downy mildew and complete control was achieved with the standard fungicides.
- None of the test treatments gave significant reductions in disease severity of Botrytis in lettuce apart from the Rovral fungicide standard.
- There were some effects of treatments on plant growth notably black spotting on Chinese cabbage with dock root extract and some cupping of leaves after rapeseed oil and neem treatments. Milk stimulated the growth of sooty moulds on chinese cabbage.

This project also evaluated the use of a range of spray conditioners to manage lettuce downy mildew (LDM) in the field:

- Both rapeseed oil and neem showed the lowest downy mildew severity and differences were significant when spraying was carried out more frequently than in the first year.
- In summary, these experiments indicate that some of the conditioning treatments show some potential to ameliorate the infestation of downy mildew on lettuce. However, further work would be needed to define under what conditions these sprays might be more effective against LDM and in raising marketable yields. This might involve assessments of varying concentrations and/or timings of the products showing the most promise (neem, rapeseed oil).
- Timings could be considered in relation to periods of risk of LDM and rainfall or irrigation (that washes treatments off the plants).
- Consideration needs to be given to the place of such treatments within organic farming systems before extensive testing programmes are carried out.

Are new biological insecticides being developed?

Currently the most widely used natural toxin against insect pests is extracted from *Bacillus thuringiensis*. This is highly specific to *Lepidoptera* species and is permitted for use in organic systems. It is highly effective so is also used in conventional systems as a means of control. Therefore it would be beneficial to identify other toxins that could be used against insect pests. A project run by Warwick HRI (Defra 2003b) investigated the potential insecticidal activity of bacterial genera *Xenorhabdus* and *Photorhabdus*, both of which are symbiotically associated with insect parasitic nematodes. The following findings arose from the project:

- Initial studies showed bacterial extracts were highly active when fed to a range of pest species belonging to at least three orders of insects.
- Characterisation of the strains showed *Xenorhabdus* was found to be ubiquitous in UK soils whereas *Photorhabdus* was less common, being found only in coastal regions around the UK.
- To identify strains with good or novel insect activity, all were tested against the pest species *Pieris brassicae* (lepidoptera), *Aedes aegypti* (diptera) and *Phaedon cochleariae* (coleoptera). Analysis of the bioassay results showed the strains had activity against a wide range of insect pests.
- The formulation was active against the aphid pest species *Myzus persicae* which is of considerable commercial interest, as currently no insect specific proteins with activity to sap feeding insects are currently available for use in pest control.
- Not all species were susceptible as no significant effect upon the cabbage root fly or the red spider mite was found.
- The toxins also showed good host specificity and could be used in combination with *Bacillus thuringiensis*, making them good candidates for environmentally acceptable pesticides.

2.4. Biological control measures

Can compost be used to suppress soil borne diseases?

There have been numerous works investigating the effects of composts on plant diseases, either applied directly to soils fed or sprayed as a compost tea. These have been reviewed in detail by Nobel and Coventry (2005) and also by Litterick et al (2004). This is a large subject that has also been covered in a separate IOTA review, so will only summarised briefly here:

- Numerous container-based studies in greenhouses or growth rooms have consistently demonstrated a suppressive effect of composts on soil-borne diseases such as damping-off and root rots (*Pythium ultimum*, *Rhizoctonia solani* , *Phytophthor*a spp.), and wilts (*Fusarium oxysporum* and *Verticillium dahliae*).
- Composts have also been shown to suppress several diseases in the field, although the effects have been generally smaller and more variable than in container experiments.
- The disease suppressive effect of compost generally increased with rate of application. Compost inclusion rates of at least 20% (v/v) were normally required to consistently obtain a disease suppressive effect, particularly in peat-based media, but significant disease suppression has been found at lower inclusion rates in soil.
- Reported levels of disease suppression were variable, even using apparently similar composted materials at the same rates.
- Sterilisation of composted materials generally resulted in a loss in disease suppressiveness, indicating that the mechanism was often or predominantly biological, although chemical and physical factors have also been implicated.
- The mechanisms and antagonistic micro-organisms involved in disease suppression are not fully understood.

Hoitink et al (1997) summarised the mechanisms thought to be responsible for suppressing pathogens in compost:

1. Competition for energy and nutrient sources and for organic matter substrate colonization. When microbial spores are stressed due to insufficient energy or nutrient sources they are less likely to germinate and colonize newly added organic matter. In many cases, pathogenic microbes (either bacterial or fungal) are poor competitors relative to beneficial organisms present in the growing medium.

2. Antagonism
Beneficial micro-organisms can destroy pathogenic micro-organism cells through lysis. They can also produce antibiotics or other substances that are toxic to the pathogenic organisms. For example, *Pseudomona*s spp. have been shown to produce an antibiotic substance that suppresses potato ? and soft rot of potato.

3. Competition for root colonization.
In situations where pathogens attack plant roots, some beneficial organisms are better able to colonize the plant roots before the pathogens can get a foot hold.

4. Induced systemic resistance (ISR) or systemic acquired resistance (SAR).
Plants can be stimulated to turn on genes that defend them against attack by pathogens. ISR can provide protection against viral, fungal, and bacterial plant pathogens and root, vascular, and foliar diseases of plants. Microbes inhabiting the micro-environment around plant roots or microbial by-products or organic matter decomposition by-products have been reported to turn on ISR genes in plants.

As stated, these mechanisms are poorly understood. As the mechanism of control depends on the microbial properties of the feedstock which is in turn dependent on a range of complex factors, it is not surprising that the degree of suppressiveness is highly variable. However there is one success story. A series of projects carried out at Warwick HRI against onion white rot (*Sclerotium cepivorum*) investigated first the use of the biological control agent, *Trichoderma viride* then later using it in combination with composted onion waste.

White rot is the most serious disease of allium crops causing losses as high as 10% in land where onions are cultivated. Furthermore, it can persist in the soil for up to 20 years, and it is estimated that 20 – 50% of onion producing land is excluded from production due to the disease. Therefore a biological control agent (BCA) that could control the disease would be a major breakthrough in onion production. Much work has been carried out at Warwick HRI to develop BCAs against the disease.

The following findings were made from initial field trials investigating the use of *T. viride* (Defra, 2002b):

- Strains of *Trichoderma viride* S17A and L4 reduced onion white rot and in one year provided control equivalent to a conventional fungicide.
- Applying the treatment at the time of drilling was most effective, with mid season stem applications having little effect.
- Glasshouse assays showed that soil type was important in determining the efficacy of the BCAs.

Further study was carried out to optimise the conditions for degrading the sclerotia of Allium white rot (Defra, 2005):

- The strains of Trichoderma, L4 and S17A could degrade sclerotia at moisture content as low as 5% but was optimum at ≥ 10% for L4 and ≥ 15% for S17A. Degradation also occurred for temperatures as low as 5°C but was greatest for temperatures above 10°C. *T. viride* L4 and S17A were therefore shown to be active against S. cepivorum for the range of temperature and soil moisture levels commonly found under UK field conditions.
- In glasshouse trials, using *T. viride* in combination with applying composted onion waste provided more effective control than just applying *T. viride* alone.

Coventry et al (2006) also showed composted onion waste to be effective at reducing the viability of the Allium white rot sclerotia in the soil. They suggested that there were two mechanisms occurring:

- Composted onion waste reduced the population of Allium white rot sclerotia in the soil, perhaps due to volatile sulphur compounds
- Trichoderma or onion waste prevented the onion plants from being infected by the allium white rot sclerotia.

Further work is in progress in order to eventually bring these techniques into commercial practice.

What is the potential for entomopathogenic fungi as a means of controlling pests?

It has been well established that fungi can be responsible for drastic reductions in the aphid population (Dunn & Kempton, 1971) and they may contribute to the mid season population crash. A large array of these fungi already exist naturally and augmenting these for biological control may provide a very host specific means of controlling the pest without causing damage to the environment. *Erynia neoaphidis* is one example of a species found in natural populations that has been observed to cause 73.5% death of the cabbage aphid population. It also infects other species of aphid including *Myzus persicae*, *Aphis facae* and *Acyrthosiphon* *pisum*. There are a number of characteristics that determine whether a fungus is a successful pathogen of aphids (Milner, 1997).

These include:

1. Rapid sporulation and germination
2. Active discharge of conidia, maximising dispersal
3. High virulence, so only a small number of conidia are needed to infect the insects
4. Short generation time
5. Production of resting spores, so that the fungus persists during unfavourable periods.

Considerable work has been done at Warwick HRI on entomopathogenic fungi and they have built up a library of suitable strains. In one trial, a series of glasshouse experiments was carried out to investigate the ability of fungal isolates to control populations of cabbage root fly (*Delia radicum*) larvae feeding on cabbage plants (Defra, 2003c).

- The best results were obtained from applying a strain of fungus (*Metarhizium anisophliae* 389.93) as a soil drench, which reduced the cabbage root fly population by up to 90%.
- Incorporating the fungus directly into the the module compost was not found to be effective.
- There was also no evidence that the fungus spread through the soil to infect other larvae suggesting that that it could only be applied as a biopesticide for short term control and not be expected to spread through the host population.

Other work (HDC, 2004) suggested that field margins may provide a reservoir of entomopathogenic fungi (especially *Erynia neoaphidis*) in both pest and non pest species of aphids on weed plants:

- Entomopathogenic fungi were shown to be capable of moving into the crop and infecting pest species.
- The fungi were mostly found within 2m of the source but could still be detected up to 12m away. Grasses such as Yorkshire fog, legumes (e.g. bird's-foot trefoil, clover) and stinging nettle, amongst others, were identified as beneficial sources of *E. neoaphidis* within agroecosystems.
- Use of fungicide killed off these fungi, reducing the beneficial effect.

Fungi have also been used to control potato cyst nematodes (PCN). In a trial at Warwick HRI, three fungal species, *Pochonia chlamydosporia*, *Paecilomyces lilacinus* and *Plectosphaerella cucumerina* were investigated. These were chosen due to their ability to survive in soil, colonise the rhizosphere of potatoes and to infect PCN (Defra, 2003d).

- A key finding in this project was that the fungi remained viable and active in the soil for at least 4 months after potatoes were harvested and were able to infect fresh cysts added to the soil. This demonstrated the ability of the fungi to remain viable within the soil and to infect eggs within cysts, without the need to colonise roots and infect emerging females. Therefore, these fungi may contribute to controlling PCN not only when a potato crop is growing but also between potato crops.
- Combinations of the fungal isolates investigated demonstrated that there was a synergistic effect of adding P. cucumerina and P. lilacinus together to control PCN populations.
- Some potato varieties such as Sante are popular in organic systems because they offer partial resistance to PCN. However, virulent strains of PCN exist that can infect Sante.

Use of the fungal isolates in combination with a partially resistant variety may reduce the selection pressure of PCN to evolve into virulent forms that can infect tolerant varieties.

Can biofumigants be used to control soil borne diseases?

Biofumigants are plants that kill off pathogens, pests or even weeds when they are incorporated into the soil. A wide range have been reported in the literature including nematode suppression in carrots by sudan grass (Widmer & Abawi, 1998), lucerne suppressing nematodes (Johnson et al., 1967) and sulphur volatiles from *Allium* species showing potential to kill soil borne pathogens (Okumara, 2000).

There has been increased interest over the years in use of mustard as a means as a biocontrol agent. The most popular species are *Brassica juncea* (sometimes known as' brown mustard' or 'Indian mustard') and *Eruca sativa* (sometimes known as 'wild rocket'). The key to their mode of action is the glucosilinate compounds within the mustard plants. When the crop is incorporated, the cells are ruptured and the glucosilinates are converted into isothiocyanates, which can act as a natural biocide. Work has investigated the effects of incorporating mustard against nematodes, slugs, wireworms (Frost et al, 2002) and diseases such as verticillium wilt, with variable degrees of success. [see review by HDC (2006)]. A number of factors can account for the degree of variability in the work. These can be summarised as:

- The glucosilinate content varies widely between varieties which are not always specified in reports. Recently there has been interest in 'caliente varieties' with a high glucosilinate content. The term 'caliente' is applied to a number of species and varieties which include the types *B. juncea* 'ISCI 99' and *E. sativa* 'NEMAT'.
- The soil type and growing conditions are also important. Generally a very large biomass of mustard is required for the biocidal effect of the mustard to be effective and this is usually dependent on large doses of nitrogen fertilizer. This limits their applicability in organic systems.
- Lastly the method of incorporation is critical. It is universally agreed that the mustard must be incorporated rapidly into the soil after being defoliated, so that the biocidal effects can have maximum impact in on the soil. Work in the Netherlands suggest that conditions are optimal when the soil is lightly compacted, irrigated then covered with plastic film for 6 – 10 weeks.

2.5 Other strategies

How can predator numbers be boosted in crops?

It is generally accepted that predators play a significant role in controlling pest populations but there is still little agreement over which types of predators are most important in controlling insect pest populations. The information on natural enemies of the cabbage aphid (*Brevicoryne brassicae*) was presented in a literature review funded by the HDC in 1999. (HDC, 1999b). Although the review focussed on cabbage aphid, many of the principles can be applied to insect pests in general. The findings of the review are summarised briefly below:

- Groups of organisms that attack aphids can be divided into aphid specific predators, polyphagous (generalist) predators, parasitoids and fungi.
- Of the aphid specific predators, there are several species of ladybird and hoverfly that feed on aphids. Hoverflies are thought to have a far greater impact than ladybirds.
- Polyphagous predators include ground beetles, spiders and lacewings. Little work has been done on the impact of polyphagous predators on vegetable crops in the field.

Although they may consume large number of aphids under laboratory conditions, when given a choice they may preferentially consume other species in the field.

- *Diaeretiella rapae* is the one species of parasitoid that can attack the cabbage aphid. However, several researchers consider *D. rapae* to be relatively ineffective. This may be due to poor searching ability, low rate of attack and poor synchronisation between the parasite and the host life cycles.

An example of a recent study that has examined the diversity of predators in different farming systems was carried out in a three year study in Switzerland which compared organic systems to low input integrated crop management systems (Piffner et al, 2003). The following findings were presented:

- In several cases, carabid populations of organic fields were significantly richer in species and abundance than in the low-input integrated crop management farmed plots. Endangered, stenoceous carabids (e.g. xero-thermophilous) and top-predators were also more abundant in the organic fields
- Wolf spiders such as *Pardosa agrestis, P. palustris* and *Trochosa ruricola* seem to be enhanced by organic management.
- Weed abundance was a significant factor affecting the carabid fauna and weed diversity influence spider fauna.

Organic systems seek to maximise this potential for control by natural predators using one or a combination of the following methods:

a) Avoiding the use of broad spectrum insecticides that kill off predators as well as the target pests
b) Introducing the predators the system to augment their numbers.
c) Providing a habitat that is favourable for predatory insects.

a) Avoiding the use of broad spectrum insecticides

This will only be reviewed briefly, as few broad spectrum insecticides are used in organic agriculture. The insecticides that could possibly have an effect on predators include soft soap, derris, spinosad and pyrethrum.

- Soft soaps, are targeted at soft bodies insects such as aphids and their effects on larger hard bodies beneficials such as beetles, hoverflies and bees is limited.
- Derris, spinosad and pyrethrum are only used in exceptional circumstances in organic systems, and derris will be phased out in the UK by the end of 2009. Therefore their impact on beneficials is likely to be limited as they are not used as routine treatments.
- Growers using these substances are also required to submit a plan to outline how damage to beneficials will be minimised. This normally entails spraying late in the evening when the activity of pollinating insects is less.

b) Introducing predators to augment their population

Introducing predators is a widely used method of controlling pests in the glasshouse but has often been met with more limited success in open systems such as field vegetables where conditions are more difficult to control.

Some of the pitfalls of this approach are illustrated clearly in a project done at Warwick HRI, where *Aleochara*, the predatory rove beetle was released in order to control cabbage root fly (Defra, 2002d). Although some level of control was achieved in some of the trials, results were highly variable. The findings are summarised below.

- Levels of control varied with species and was only considered acceptable (a reduction in pupal numbers of >75%) for Chinese cabbage and turnip.
- Levels of control were far less than applying conventional insecticides, although organic systems do not normally seek to eliminate the pest completely.
- Timing of release of the predator was important. The best control was achieved when *Aleochara* was released to coincide with 70% egg laying of the cabbage root fly.
- The level of control was quite successful in one season but very unpredictable in another. Too many uncontrollable factors made the results difficult to explain.
- *Aleochara* is a generalist predator and when given a choice also fed on other invertebrates thought to be important in the control of the cabbage root fly.
- High numbers of predators needed to be released to achieve control as, on average, each beetle only killed between two to five cabbage root fly larvae. This would be impractical and expensive. It also required a knowledge of how many cabbage root fly would enter a particular field which is difficult to predict.

The variability of success in augmenting beneficials can be put down to a multitude of factors and many would argue that it is always going to be doomed to failure if the environment is not favourable for the predator in the first place. Therefore promoting environmental features that boost predator numbers should be a vital part of any organic system.

c) Providing a habitat for predators

A number of measures can be taken to encourage predators into crops. These can be summarised as providing a favourable environment within the crop such as use of mulches, sowing attractant plants and leaving buffer strips and margins around fields.

Use of mulches

The area within the crop can be manipulated to encourage predators. Key findings from the work are:

- The use of straw or compost mulch is thought to increase the populations of generalist predators such as spiders (Mans et al, 2008), or ground dwelling beetles (Johnson et al, 2004) but effects tend to be quite small and inconsistent.
- It is likely that mulches may have other beneficial effects on pest infestation such as reducing the ability of the pests to locate the host plants, although little work has been done to test this.
- Ponti et al (2008) also found that calabrese fertilised with compost not only had a lower aphid infestation but attracted a greater number of predators into the plots.

Sowing attractant plants

Most attention has been given to sowing flowering plants and it is widely acknowledged that flowering plants encourage natural enemies (Verkerk, 2001; Solomon *et al*, 1999). A summary of the work includes:

- Flowers are vital sources of amino acids and carbohydrates which many species of beneficial insects including hoverflies, lacewings and some species of ladybirds require for egg production and energy (Altieri & Whitcomb, 1979). Nectar and pollen are also the sole energy resources for adult parasitic wasps (HDRA, 1993).
- Many species of flowering plant have been documented as being attractive to beneficial insects. However, floral attractiveness is dependent on a number of factors including colour, pollen, nectar and morphology (Colley & Luna, 2000) and there remains a lack of consensus as to which plants are most attractive.
- Identifying the plant species, quantity and planting management that supports beneficial insects is important, otherwise pest populations may be encouraged (Dufour, 2000) or activity, such as egg laying, not significantly or positively influenced (Morris & Li, 2000).
- Phacelia is commonly touted as a very effective species for attracting predators such as hoverflies, but there are many species, particularly those that are in the Umbelliferae (now Apiacae) family such as yarrow (*Achillea millefolium*), cow parsley (*Anthriscus sylvestris*) and hogweed (*Heracleum sphondylium* L.) that are more attractive (Northing, 2003). One reason for the popularity of phacelia is that its long flowering period and vigorous growth make it easy to establish and grow.
- Work carried out by Garden Organic (Sievwright et al, 2006) showed that corn marigold (*Chrysanthemum segetum*), fennel and coriander were all at least as effective at phacelia at attracting predatory insects. The study showed that different plants were more effective at different times of year during their flowering periods. Coriander and Phacelia were most effective early in the season in June and July, Corn Marigold in August and Fennel in September and October. Therefore sowing a mixture of plants may extend the period when flowers are present to attract predators.
- All of these plants can be established as permanent banks within crops, as they will perpetuate themselves by self seeding.
- It is particularly important to augment predator numbers early in and late in the season, when pests can be a problem but predator numbers are insufficient to provide control.

Leaving buffer strips and field margins

The importance of leaving species rich field margins to build up levels of beneficial insects is well established:

- Northing (2003) found that crops with a flower rich margin showed a 50 % reduction in peak aphid populations compared to those with no field margin. The duration of aphid infestation was also reduced.
- Denys and Teja Tscharntke (2002) also found that the number of and diversity of predators increased over a period of years, suggesting that older established habitats are more effective than newly sown ones.

Can distraction techniques such as companion planting or strip cropping reduce pest infestation?

It is now well accepted that growing a crop with another species (undersowing, companion planting, inter-cropping or leaving weeds to grow) can decrease pest infestations significantly (O'Donnell and Coaker, 1975; Finch and Edmonds, 1993; Sengonca et al. 2002). Finch and Collier (2000) proposed that this is because the presence of a non-host plant species reduces pest colonisation. Insect pests such as cabbage root fly seek out the host crop by making a series of ‘appropriate / inappropriate landings’. After initially locating the crop, an insect lands on any green surface. If the insect recognises this as a host plant (an ‘appropriate

landing') it makes further short flights, landing on additional leaves to assess the overall suitability of the plant. It must make several consecutive 'appropriate landings' to be sufficiently stimulated to lay eggs. If it makes an 'inappropriate landing' on another plant species, such as a companion plant or weed, it must begin the searching process again and may fly away. Consistent with this, there was a 36-82% reduction in egg-laying by the cabbage root fly when cauliflowers were planted amongst 24 other non-host plant species (Finch, et al., 2003). However, strategies such as undersowing with clover
can result in yield penalties of 30-40% (Finch and Edmonds, 1993) through plant competition. There are a number of ways that mixed systems can be managed in order to maximise the benefits of pest control without large sacrifices in yield:

a) Controlled weeding

A review of the various work and models characterising weed, pest and crop yield interactions was undertaken by Warwick HRI (Defra, 2006). The following recommendations were made from this review:

- There is a trade off between crop yield and pest control. Yield loss (up to 30%) due to competition may be tolerable as an alternative to severe pest damage, in situations where infestation levels are high.
- The strategy of allowing weed presence for a limited period whilst maintaining a weed : crop ratio (total dry weighs per unit area) above a threshold can provide some protection against pest damage. The threshold is dependent on the pest, crop and weed species involved.
- In practice, planting into a background of natural flora is probably the most practical way of achieving this protection. However, the weeds would need to be well-established before the cabbage was transplanted to achieve the required weed : crop ratio. Further information is needed on the development of natural floras, and on the effect of different weed species compositions.
- Weeds in close proximity to the crop do reduce pest colonisation, as seen in other studies. Further information is needed on the spatial characteristics of plant competition to enable more realistic and practical strategies to be evaluated.

b) Strip intercropping

The effects of planting strips of brassicas alternating with red clover on pest infestation were evaluated by Bjorkman et al (2007). In this study, intercropping reduced infestation of cabbage by the turnip root fly (*Delia floralis*) by 43% compared to the monculture controls. Key points from this work are:

- This effect was greatest at the border between the monoculture and the intercrop (up to 68%). This was because the turnip fly has a greater chance of being attracted to the monocrop in preference to the intercrop when it is close to the border.
- This technique presents challenges with crop management that may outweigh the benefits gained from reduced pest infestation. One of the challenges includes reducing the vigour of the clover stand to reduce competitive effects.
- In a similar study Bjorkman (2006) used root pruning as a technique to reduce clover vigour. However this is a technique that is not commonly used in the UK, can be expensive and only performed on light soils.
- A simpler solution may be to choose a variety of clover that is not very competitive, such as subterranean clover (*Trifolium subterraneum*) although this has not been tested extensively.

c) Module sown companion plants

- Module sown companion planting is a relatively recent idea. The theory is that by sowing a companion plant in the module at the same time as the crop plant, the companion plants are targeted close to the crop, where they will disrupt egg laying. However, because they are selectively targeted, a much lower population of companion plants is needed than if they were sown in the field, so competitive effects should be reduced.
- This idea was tested in a small scale field trial (Rosenfeld et al, 2006) where a 48% decrease in egg laying by the cabbage root fly was observed when birdsfoot trefoil (*Lotus corniculatus*) was sown in the modules at the same time as calabrese plants. The module sown companion plants did not compete with the crop or decrease yield.
- This technique is already used by a number of commercial organic brassica growers in the UK as there is very little extra cost to the plant raiser. It does, however require further refinement. If the companion plants are still small at the time when the brassica crop is first weeded mechanically with a steerage hoe, they are susceptible to being buried, and never appear again.
- Currently more work is being done at Warwick HRI (HDC, 2008), to find suitable species that provide protection against the pest and are robust but do not compete strongly against the crop. The ideal species may not be the same for all crops or soil types.

Can planting arrangement reduce disease?

a) Use of mixtures

The use of mixtures has the potential to reduce the build up of inoculum during the season and to slow the spread of the disease in the growing crop and has been used in cereals. In the DOVE project (Defra, 2002a) the potential for lettuce varietal mixtures to manage lettuce downy mildew (LDM) in a late summer crop was evaluated over two seasons.

- In neither season did an alternating row layout appear to affect disease development, although, overall, head weight did increase slightly in both years.
- However, a complete mixture layout, within and between rows, had a considerable effect, with disease overall reduced by more than half in the mixture relative to the mean of the pure stands.

b) Use of spacing

As part of the DOVE project the effects of plant spacing, to manage LDM in field grown lettuce was evaluated (Defra, 2002a). Spacing is known to affect disease development in crops and organic crops are often planted at wider spacing than conventional crops to reduce disease incidence. The wider spacing had little effect on LDM severity, plant growth or yield, but marketable head weight was slightly higher at wide spacing.

c) Use of coloured mulches

In the DOVE project a trial was carried out to evaluate the potential of mulching to manage LDM in field grown lettuce (Defra, 2002a). Mulches have been shown to improve crop yield due to various causes including moisture retention, weed control and elevated soil temperatures. Work has also shown that light reflected from different coloured mulches can affect root and leaf development and may even affect disease development on crops. Key points from the work are:

- Downy mildew appeared within two weeks of planting in Norfolk and showed less severe infection in black and blue polythene treatments but these differences were not maintained.
- Mulch had little or even a negative effect on LDM severity and it was concluded that mulch, in itself, is unlikely to offer a commercially viable method of LDM control.

d) Use of soil amendments

In the DOVE project a series of glasshouse trials were undertaken to investigate the potential for using organic soil amendments as part of disease management strategies in organic horticultural production (Defra, 2002a). The use of amendments was evaluated with a range of specific crop-disease combinations: 1) lettuce damping off (*Rhizoctonia solani*), 2) pea foot rot complex (*Fusarium* spp., *Pythium* spp., *Phoma medicaginis* var pinodella), 3) brassica club root (*Plasmodiophora brassicae*) and 4) potato canker/black scurf (*Rhizoctonia solani*). The range of amendments used was similar in the various experiments and represented either amendments that organic growers would normally use (e.g. green manures, manure composts) or those available commercially and eligible under organic standards (e.g seaweed meal, composts).

- Organic amendments had some effects on plant disease development but that these effects were complex.
- There were often significant differences between treatments and some reductions in disease compared with unamended controls.
- *Rhizoctonia* in lettuce and black scurf were reduced by rye, cabbage and chitin, whilst straw and chitin reduced club root severity.
- The project reported that organic amendments are not always beneficial from a disease management perspective and in certain situations might exacerbate a problem.

2.6 Potential for new products

What new products are available to organic growers?

a) UV blocking film

The effects of excluding ultraviolet light has attracted interest in controlling both insect pests (Kumar and H-M. Poehling, 2006) and disease (West et al , 2000) and is attractive to both organic growers and conventional growers using integrated pest management. Special films designed to exclude UV light disrupt the insects' flight behaviour and ability to seek out the host crops (Antignus, 2000). This has been shown in a number of studies to reduce the incidence of pests such as whitefly (*Bemisia tabaci*), thrips (*Ceratothripoides claratris*), and aphid (*Aphis gossypii*). This not only reduced pest damage but dramatically reduced incidence of virus from 96 – 100% infection to 6 –10 %. The film can also reduce incidence of disease by inhibiting the germination of conidia, as shown with *Botrytis cinerea* in strawberry plants (West et al , 2000).

Recent work carried out by Organic Centre Wales (Morris, 2004) investigated a range of vegetable and salad crops growing in tunnels either covered by standard polythene or UV excluding film. This study did not report measured values but provided a good visual record that showed clear differences between the two types of tunnels. These included:

- Pest damage in brassica crops, especially slugs was reduced by the UV blocking film
- Aphid numbers on salad crops was dramatically reduced by the UV blocking film

- Plants growing under the UV blocking film showed increased rates of growth and development and attained a larger final size.
- Lettuce plants attained a larger size before they became infected with downy mildew. This therefore meant that after the removal of infected leaves, there was a much greater head of lettuce that was saleable.
- UV blocking film did not have any effect on downy mildew incidence or other diseases.

b) Compost teas

Compost teas have been used for centuries to promote the health of plants, but we still do not fully understand their mode of action. As with the use of compost to suppress disease in the soil, it is thought to be the biological properties of antagonistic organisms that provides the disease control properties.

The use of compost teas is more popular in the US with many devices and products available. The topic is covered in the review by Litterick et al (2004). More recently the literature has differentiated between the production of aerated compost tea (ACT) and non-aerated compost tea (NCT). Most work has been done on NCT, and if the distinction is not mentioned, then it is most likely to be this type. The production of aerated and non-aerated compost teas both involve compost being fermented in water for a defined time period. Both methods require a fermentation vessel, compost, water, incubation, and filtration prior to application. Nutrients may be added prior to or following fermentation and additives or adjuvants may be added prior to application.

There is a wide range of literature showing that compost teas provide some control of diseases. This is summarised below:

- Compost tea has been used to control plant diseases both *in vitro* and in the field. Diseases that have been controlled under field conditions include: *Phyopthora infestans* in potatoes and tomatoes, *Alternaria solani* in tomatoes and *Botrytis cineraria* in lettuce, tomatoes and peppers. Most of the preparations used were an extracts from animal manures mixed with straw.
- Control that is achieved *in vitro* does not always translate into effective control under field conditions.
- Compost production methods varied greatly as did the input materials used and the preparation of the tea.
- Efficacy of control varied greatly between studies but as there were so many factors that differed, it made it difficult to draw firm conclusions.
- There was little work published to show the efficacy of ACT and little scientific evidence to show that they were more effective in controlling plant diseases than NCTs.

c) Ferric phosphate as a control against slugs

Ferric phosphate has been shown to act as an effective molluscicide (Speiser &Kistler, 2002, Gengotti et al, 2008). It is not a particularly new substance but has only more recently been registered for use in organic systems under derogation. Details from the US Environmental Protection Agency suggest that, despite being toxic to slugs its impact on the environment or human health is minimal:

- It has very low mammalian toxicity with there being no evidence to suggest that it has adverse effects on the immune or nervous system

- It has low solubility so is unlikely to transfer to drinking water

- It also has extremely low avian toxicity (unlike conventional slug pellets)
- Submitted studies involving ground beetles, rove beetles and earthworms demonstrated that the product will not affect these organisms at up to two times the maximum application rate.

d) Using nematodes as a biocontrol agent against slugs

The nematode, *Phasmarhabditis hermaphrodita* occurs in nature and is a parasite of slugs. More recently, this species has been used as a biocontrol agent for slug control in organic systems. Formulated nematodes are mixed in suspension and applied as a soil drench. Advice from manufacturers recommends that it is applied once every six weeks. There has been mixed success in studies using this as a method of control. One study (Defra, 2002c) found that it was effective in some trials, whereas other work (Gengotti et al, 2008) found that it offered no protection at all. There are a number of factors that can be drawn from various work that must be taken into account when using this as a method of control.

- The formulation is expensive so is only worth applying to high value horticultural crops
- Nematodes only live in the soil water, so they will only parasitise slugs that are under ground.
- Lack of kill to surface dwelling slugs means that the formulation takes time to reduce the slug population during which time, considerable crop damage may occur. It is therefore best to apply it as a longer term means of control.
- Size and species of slug is important (Speiser et al, 2001). In the species, *Arion lusitanicus*, smaller slugs are killed effectively by the nematode, whereas larger slugs remain unaffected. However, *Deroceras reticulatum* is affected by the nematode irrespective of its size.
- Nematodes alone are unlikely to provide full control of slugs. They should be used as one of a number of control measures in organic systems.

e) Potassium bicarbonate as a disease control

Potassium bicarbonate is not a particularly new fungicide but was only granted approval for use as horticultural fungicide in 2005 by the Pesticide and Safety Directorate, UK.

- Although it has been tested on a range of diseases (reviewed in Defra (2007)), it has shown most promise against powdery mildew (*Sphaerotheca fuliginea*) in cucurbit crops (eg. Reuveni et al, 1996).
- It has only been recently registered for organic use by certifying organic bodies in the UK, for use under derogation. A derogation will only be granted if it is to be used as an alternative to a copper based spray.
- With the likely possibility of copper being phased out, there is the need for alternative strategies for controlling *Phyphthora infestans* in organic potato crops. Although potassium bicarbonate is touted as a possible alternative, there is surprisingly little peer reviewed work in the literature on its effectiveness against blight.
- In environmental terms potassium bicarbonate is definitely preferable to using copper sulphate. As a substance, it is fairly ubiquitous in many forms in the environment and as it

is permitted as a food substance is highly unlikely to have any adverse effects on human or mammalian health (US EPA, 1997)

3. Analysis and Conclusions

One of the key mantras of organic systems is that prevention is better than cure and this applies particularly for pests and diseases. This can make pests and diseases a difficult topic to research as it necessitates a systems approach whereby many factors are taken into account. Research into control of pests and diseases in organic systems has in the past been at a disadvantage compared to conventional control measures. Much research into organic control generates knowledge that can be put into practice by growers, but this does not have the commercial vested interest of developing a pesticide that can be marketed. However with increased concern over the harmful effects of many pesticides, there is increased interest in developing alternatives, and many of these methods used in organic systems will eventually find their way into conventional systems as well. It is difficult to draw general conclusions from such a wide topic, so the analysis and conclusions are divided into a range of topic areas. If one point is to be stressed, it is that it is unlikely that one of these control measures alone is going to provide protection to a crop. A range of measures including a management and systems approach foremost, should be employed, with direct control measures applied as a fall back when pest and disease pressure is high.

Management and rotations

Systems approaches to diseases

This review focussed on blight (*Phytophthora infestans*) as an example of how systems approaches can be used to control disease. The blightmop project (Tam et al, 2004) indentified that although copper is still used extensively in some countries, in others it is banned and cultural measures are the only way of controlling the disease. Use of varieties and early planting were the key measures used, but further ways of combating the disease are needed if organic potato crops are to be grown economically.

Forecasting systems

Forecasting systems can form an extremely valuable tool for the organic grower as it helps them to predict when the most serious outbreaks are likely to occur so that appropriate control measures can be taken. There are a number of forecasting systems that have been developed and are widely available for growers to use. The key systems include:

- Blight watch – a system warning when Smith periods (weather conditions highly conducive to blight infection) occur.
- Cabbage root fly and carrot forecasts provided to HDC members.
- Aphid monitoring collections collated by IACR Rothamstead.

Research to develop systems for other pests and diseases will provide further tools for organic and conventional growers.

Seed treatments

In conventional systems, fungicides and insecticides are applied to seed as a matter of course because it is cheap and easy to do. As this is not permitted in organic systems, other methods of controlling seed borne diseases have been developed in an EU funded project, Seed Treatments for Organic Vegetables ('STOVE') (Amien, 2006) The most widely used treatments that have been adopted are hot water and aerated steam. These have been used for controlling *Septoria appiicola* which is one of the most devastating diseases in celery. Experience with growers showed that there were some initial problems with achieving a balance between treating the seed successfully for the disease without reducing germination. There is also the potential for the use of microbial preparations as these provided highly effective control and further work should be done to develop them as commercial seed treatments.

Varieties

Organic variety trials

Varieties selected to grow well in conventional systems are not necessarily the best ones to grow in organic systems. Defra funded trials for organic varieties of vegetables for 17 years. The NIAB organic variety handbook (see NIAB, 2007) was a key output from this work and the last one was published in 2007. Although the programme is now discontinued, there are other projects (eg Defra, 2009) on breeding for low input systems and these may provide some useful information to organic growers.

Sárpo varieties

Sárpo varieties show a remarkable resistance to blight. This was particularly evident in trials in 2007 and 2008 when blight pressure was extremely high, and these varieties continued to produce a green canopy when other varieties were completely defoliated by the disease. A number of varieties are now commercially available including Axona, Mira and Kifli. With the threat of increasingly virulent strains of blight and wetter summers, and perhaps further restriction on use of copper, these are likely to become more popular in organic systems.

Breeding resistance

Breeding for downy mildew (*Peronospora parasitica*) resistance in brassicas has provided a good example of how vulnerable a single gene resistance is to breaking down. Work at Warwick HRI (Defra, 2003a) has researched into breeding varieties with more than single gene resistance and also investigating resistance to white blister (*Albugo candida*). An interesting finding from the work was that it demonstrated how traits for other desirable characteristics can be unintentionally lost when breeding solely for one trait. It emphasised the importance of breeding for traits in parallel when selecting. On a wider note it shows the need for preserving a wide gene pool in germplasm collections to ensure that we have the genetic resources to cope with future challenges.

Pesticide inputs

Although organic systems place emphasis on systems that prevent pests and diseases, organic growers also require environmentally acceptable products that control pest outbreaks when they do occur. Bacillus thuringiensis (BT) is one such product that is highly effective at providing control without harming non target species. With the withdrawal of some products such as Derris (although this was only used in rare cases), there is the need for other products to provide control. The DOVE (Defra, 2002a) project investigated a range of these products. Rapeseed oil and neem showed the most promise against downy mildew in lettuce and further work should be done to evaluate these in a wider range of circumstances. Work at Warwich HRI (Defra, 2003b) also found that strains bacteria in the genera *Xenorhabdus* and *Photorhabdus* were effective against a range of pests including diamond back moth and peach potato aphid.

One hurdle in developing new products as pesticides is that they have to be passed through the UK Pesticide and Safety Directorate before they can be marketed for use as pest control. This can be a time consuming and expensive process.

Biological control

Using compost to suppress plant diseases

The literature on the effects of compost on disease suppression can be confusing and conflicting. Although good suppression is often achieved in pot experiments, results in the field appear to be more variable. (see Noble and Coventry, 2005). With the variability in starting materials, methods of production and testing methods, all which are often not clearly specified, it is not surprising that results differ between studies. The most consistent results have been achieved through applying composted onion waste in combination with *Trichoderma viride* which has shown good promise in controlling onion white rot (Coventry et al, 2006), a disease causing major loss in onion crops. With further work, it is likely that this is a technique that could be used by growers in the future.

Use of entomopathogenic fungi

Entomopathogenic fungi occur in nature and have been observed to cause large reductions in insect populations. The species *Erynia neoaphidis* is the most effective at killing aphids and is thought to contribute to the mid season population crash. Warwick HRI have tested a number of other fungi with potential that include *Metarhizium anisophliae* 389.93 against cabbage root fly (*Delia radicum*) (Defra, 2003c) and a range of species against potato cyst nematode (Defra, 2003d). In theory entomopathogenic fungi provide the potential for a highly effective species specific biological control agent. Success depends on the ability of the fungi to spread and colonise the insect population rapidly and this can be dependent on environmental conditions. Further work needs to be done to understand the environmental conditions under which these agents are successful, so that products can be developed for commercial use.

Use of biofumigants

There are many plants that produce chemicals as a self defence mechanism. Recently there has been some interest and a degree of aggressive marketing of caliente type mustards that have a high glucosinilate content. These are grown as a cover crop then incorporated into the soil and have been touted to rid the soil of many problems such as nematodes, diseases, wireworms and weeds. A review of the work (HDC, 2006) showed that there was a great deal of variability in the work. The most successful results are dependent on rapid incorporation of a large amount of biomass. These have almost always been achieved under conventional conditions where large amounts of synthetic nitrogen fertiliser are applied, making them less applicable to organic systems. Also the growing of another brassica in a rotation limits their use in field vegetable systems.

Other strategies

Attracting natural enemies into crops

It is widely agreed that natural enemies play a significant role in controlling insect pests. Unfortunately, their role in field situation is still somewhat unpredictable, as a complex web of interacting factors are involved. Natural enemies of the aphid have been studied extensively especially the cabbage aphid, and this work is presented in a review by the HDC (1999). This showed that there is still not agreement over which are the most important species controlling aphid populations. Specialist predators including ladybirds, hoverflies, gall midges, parasitic wasps and generalist predators such as carabid beetles, spiders and lacewings are all thought to play a role. In an organic system, a single universal species should not be expected to provide control, rather a diverse range each contributing to controlling the pest population. Diversity also buffers against changes in climate that may favour one predator over another. Unlike glasshouses, introducing predator species into field vegetable crops has met with limited success in the UK, and more effort should be concentrated on providing an environment that is favourable for predators. They may be attracted into crops both by sowing attractant species (Umbelliferous species are particularly good attractants) and leaving wild margins around the crop. Again diversity is key. A diverse range of plants will provide a wider range of beneficial species providing better control of pests.

Using distraction techniques

There has been much work to show that plants growing against a green background (either of weeds or an undersown plants) suffer fewer pest problems than those growing in bare soil (eg Finch and Collier, 2000). Although this is undeniably an effective method of pest control, it does present problems with crop management. Maintaining the balance between achieving pest control but preventing the undersown plants from competing against the crop is usually difficult to achieve. It is also highly dependent on season, soil type and crop type, so it is difficult to construct a universal set of recommendations for all crops. Various methods have been tried including strip cropping, root pruning (to reduce the vigour of the undersown plants) and sowing companion plants in the modules (for transplanted crops). All of these require further refinement before they can be taken up as commercial practice. Sowing companion plants alongside the crop plants in modules and transplanting them together has shown some promise, and is practised by some commercial plant raisers. The method still requires further refinement, to select ideal species for different situations and this work has been carried out by the HDC (2008).

Planting arrangement

A range of planting practices have been tried against lettuce downy mildew (LDM) including varying plant spacing, mixing varieties, and using coloured mulches. (Defra, 2002a). Of these mixing varieties was the most successful in reducing LDM. Unfortunately it was only effective if the varieties were mixed up within the rows and not if they were only mixed up between rows. This would undoubtedly present logistical problems for harvesting lettuces in large scale systems, but may be applicable to smaller scale systems or using leaves in mixed salad packs. The other techniques showed little success in controlling the disease.

Potential for new products

There is always going to be the need for products that can be applied for pest control in organic systems. Some existing products, particularly copper products need to be reviewed and are likely to be eventually replaced. Use of copper has always provided ammunition for the anti organic lobby and many growers choose not to use it partially for this reason. Unfortunately potato blight still remains a serious problem for organic growers, and there are few alternative products that provide adequate control. Compost teas have provided a degree of control in some work, but their effects are inconsistent and cannot be relied upon. Potassium bicarbonate has recently been permitted for use, under derogation, by certifying bodies to be used as an alternative to copper sprays.
Other products that have been recently permitted by certifying bodies include ferric phosphate for the control of slugs. As this kills slugs on the soil surface it may be used in conjunction

with nematode products that kill slugs beneath the soil. However, it can only be used under derogation, and certifying bodies are keen that it does not become a blanket control measure. As with all organic methods of control it should form one of a range of control measures in an integrated system.

4. References

Altieri, M. A. and Whitcomb, W.H (1979) The potential use of weeds in the manipulation of beneficial insects. Horticultural Science 14:12-18

Amein, T.,Wright, S.A.I.,; Wikström, M, Schmitt, A., Koch, E., van der Wolf, J, Groot, S.; Forsberg, G., Werner, S. and Jahn, M. (2006) Non- chemical methods of seed treatment for control of seed- borne pathogens on vegetables. http://orgprints.org/8532/ Centre for organic Seed Information (COSI) www.cosi.org.uk

Anon, (2005) Organic Centre Wales Technical Note 2: Evaluation of Sárpo potato varieties, 2004. Organic Centre Wales. http://orgprints.org/10805/

Antignus, Y (2000) Manipulation of wavelength-dependent behaviour of insects: an IPM tool to impede insects and restrict epidemics of insect-borne viruses Virus Research 71:213-220

Björkman, M.; Hambäck, P.A. and Rämert, B. (2007) Neighbouring monocultures enhance the effect of intercropping on the turnip root fly Delia floralis. Entomologia Experimentalis et Applicata 124: 319-326

Björkman, Maria; Båth, Birgitta; Hambäck, Peter; Rämert, Birgitta and Thorup-Kristensen, Kristian (2006) Intercropping systems - Optimising crop protection and reducing competition. Paper presented at Joint Organic Congress, Odense, Denmark, May 30-31, 2006. http://orgprints.org/7480/

Colley, M.R. and Luna, J.M. (2000) Relative attractiveness of potential beneficial insectary plants to aphidophagous hoverfly. Biological control. 29:1054 - 1059

Coventry, E., Noble, R., Mead, A., Marin, F. R., Perez, J. A., and Whipps, J. M. (2006) Allium white rot suppression with composts and Trichoderma viride in relation to sclerotia viability. Phytopathology 96:1009-1020.

Defra (2002a) Development of disease control strategies for organically grown field vegetables (DOVE) (OF0168). Report, Boxworth, ADAS Consulting Ltd. http://orgprints.org/8138/

Defra (2002b) Biological control of allium white rot. - HH1828SFV Final project report http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=7933 - RelatedDocuments

Defra (2002c) Integrated control of slug damage in organic vegetable crops OF0158 final report http://orgprints.org/6786/

Defra (2002d) Biocontrol of cabbage root fly by release of predators. - HH1830SFV Final project report
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=7969 - RelatedDocuments

Defra (2003a) Variability in Fungal Pathogens. Final Project report HH0916SFV http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=9142 - RelatedDocuments

Defra (2003b) Identification and characterisation of novel toxins for use in the control of insect pests in horticulture. HH1829SFV. Final Project report http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=7935 - RelatedDocuments

Defra (2003c) Fungal control of diptera HH1832SFV Final Project report http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=7939 - RelatedDocuments

Defra (2003d) Impact of nematophagous fungi on the regulation of potato cyst nematode populations – HP0115, Final project report

Defra (2005) Integrated of biological control agents for sustainable control of Allium white rot – Final project report HH3204SFV http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=10608&FromSearch=Y&Status=3&Publisher=1&SearchText=Allium&SortString=ProjectCode&SortOrder=Asc&Paging=10 - Description

Defra (2006) Using weeds to reduce pest insect numbers in organic vegetable crops - a desk study OF0329 http://orgprints.org/6762/

Defra (2007) Potential of simple salts to partially substitute for conventional foliar fungicides on crops Project report PS2117

Defra (2009) Plant breeding and variety selection for organic cropping - OF0375http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=14953&FromSearch=Y&Publisher=1&SearchText=OF0375&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

Denys, C. and Tscharntke, T. (2002) Plant-insect communities and predator-prey ratios in field margin strips, adjacent crop fields, and fallows Oecologia (2002) 130:315–324

Dufour, R. (2000) Farmscaping to enhance biological control. ATTRA publication #CT065.

Dunn, J.A and Kempton, D.P.H. (1971) Seasonal changes in aphid populations on Brussels sprouts. Annals of Applied Biology. 68:223-244

Finch, S. and G. H. Edmonds (1993). "Undersowing cabbage crops with clover- the effects on pest insects, ground beetles and crop yields." IOBC/WPRS Working Group Meeting Integrated Control in Field Vegetables: 159-167

Finch, S. and R. H. Collier (2000). Entomologia Experimentalis et Applicata 96: 91-102.

Finch, S. and R. Collier (2003). Insects can seed now the weeds have gone Biologist 50: 132-135.

Frost, D; Clarke, A and McLean, B M L (2002) Wireworm Control using Fodder Rape and Mustard – evaluating the use of brassica green manures for the control of wireworm (*Agriotes* spp.) in organic crops. Report, ADAS Pwllpeiran. http://orgprints.org/10863/

Gengotti, S ; Censi, D and Curto, G (2008) Evaluation of active ingredients and nematodes against slugs and snails on organic lettuce. Poster presented at Cultivating the Future Based on Science: 2nd Conference of the International Society of Organic Agriculture Research ISOFAR, Modena, Italy, June 18-20, 2008.

HDC (1999a) Carrot fly and cabbage root fly: improved systems for forecasting attacks. FV 13a

HDC (1999b) Brassicas: Impact of natural enemies of the cabbage aphid in field brassica crops. FV 218

HDC (2000) A forecasting system for dark leaf spot. FV53d

HDC (2001) Outdoor lettuce: Refinement and field validation of forecasts for the aphid pests of lettuce foliage FV 162e

HDC (2004) Novel Strategies for Aphid Control using Entomopathogenic Fungi FV 221

HDC (2006). Literature review of the biocidal crops mustard (*Brassica juncea*) and wild rocket (*Eruca sativa*). Central Science Laboratory / HDC project FV 273

HDC (2007) Biology and control of currant-lettuce aphid (*Nasanovia ribisnigri*) FV 279.

HDC (2008) Brassica: companion planting for pest control, FV 251

HDRA (1993) Step by step organic gardening: gardening with beneficial insects for natural pests control. Henry Doubleday Research Association, Ryton. Coventry.

Hoitink, H. A. J., Stone, A. G., & Han, D. Y. 1997. Suppression of plant diseases by composts. HortScience. 32:184-187.

Johnson, J.M.; Hough-Goldstein J. A.; Vangessel, M. J.; (2004) Efects of straw mulch on pest insects, predators, and weeds in watermelons and potatoes. Environmental Entomology 33: 1632-1643

Johnson, LF, Chambers, A.Y. and Reed, H.E. (1967) Reduction of root-knot of tomatoes with crop residue amendments in field experiments. Plant Disease Reporter 51:219-222

Kumar and H-M. Poehling (2006) Environmental Entomology 35:1069-1082. UV-blocking Plastic Films and Nets Influence Vectors and Virus Transmission on Greenhouse Tomatoes in the Humid Tropics

Litterick, M.; Harrier L.; Wallace, L.; Watson, C. A. and Wood, M.(2004) The Role of Uncomposted Materials, Composts, Manures, and Compost Extracts in Reducing Pest and Disease Incidence and Severity in Sustainable Temperate Agricultural and Horticultural Crop Production—A Review. Critical Reviews in Plant Sciences 23: 453–479

Manns, Mrs. Hida R.; Murray, D. L. and Beresford, D. V. (2008) The use of mulch to increase Spider (Arachnidae) numbers; a habitat approach to biological insect control. Poster presented at Cultivating the Future Based on Science: 2nd Conference of the International Society of Organic Agriculture Research ISOFAR, Modena, Italy, June 18-20, 2008. http://orgprints.org/11936/

Milner, R.J. (1997) Prospects for biopesticides for aphid control. Entomophaga 42,227-239

Morris, L. (2004) Ultraviolet blocking greenhouse polythene covers for insect pest control on organic crops: May 2003 - September 2004. Report, Organic Centre Wales.

Morris, M.C. and Li, F.Y (2000) Coriander (*Coriandrum sativum*) "companion plants" can attract hoverflies and may reduce pest infestation in cabbages. New Zealand Journal of Crop and Horticultural Science 28:213-217

NIAB (2001) Varieties of field vegetables and potatoes for organic production and marketing CSG15 MAFF Final Project report MAFF OF0142 http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=7261#Description

NIAB (2004) Varieties of field vegetables and potatoes for organic production and marketing SID5 Defra Research Project Final report. Defra- OF0304. http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=10399#Description

NIAB (2005) NIAB Vegetable Associate Scheme, one-year results. Organic Potatoes 2005. http://www.cosi.org.uk/web/cosi/cosi.nsf/VarietyTrials/6B00988574AF063E802570D800366D4E

NIAB (2006). NIAB Vegetable Associate Scheme, one-year results. Organic Potatoes 2006. Issue 141. http://www.cosi.org.uk/web/cosi/cosi.nsf/VarietyTrials/9220C2513354EF4280257237003DBDB9

NIAB (2007) Organic Vegetable Handbook, NIAB publications

NIAB (2007) Varieties of field vegetables and potatoes for organic production and marketing (continuation of OF0304) - OF0346. http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=13024#Description

Noble, R. & Coventry, E (2005) Suppression of soil-borne plant diseases with composts: A review Biocontrol Science and Technology 15: 3-20

Northing, P. (2003) 3D Farming: Making biodiversity work for the farmer: a hoverfly's perspective. http://www.csl.gov.uk/science/organ/environ/entom/3Dfarming.pdf (accessed 09/03/09)

O'Donnell, M. S. and T. H. Coaker (1975). Potential of intra-crop diversity for the control of brassica pests. Proceedings 8th British Insecticide and Fungicide Conference. xx: 101-107

Okumura, M. (2000) Soil microbial properties in various rotation systems and ecological control of *Fusarium* root rot of kidney beans in the Toakachi district. Report of Hokkaido Prefectural Agricultural Experiment Stations No97, 102pp

Pfiffner, Lukas and Luka, Henryk (2003) Effects of low-input farming systems on carabids and epigeal spiders a paired farm approach. *Basic and Applied Ecology* 4:pp. 117-127.

Ponti, L.; Altieri, Miguel A. and Gutierrez, A. P. (2008) Compost enhances parasitization of *Brevicoryne brassicae* (L.) by *Diaeretiella rapae* (M'Intosh) in broccoli under different levels of crop diversification and plant competition. Poster presented at Cultivating the Future Based on Science: 2nd Conference of the International Society of Organic Agriculture Research ISOFAR, Modena, Italy, June 18-20, 2008.

Potassium bicarbonate (073508) and Sodium bicarbonate (073505) Fact Sheet 1997

Reuveni, M Agapov, V. & Reuveni, R. (1996) Controlling powdery mildew caused by *Sphaerotheca fuliginea* in cucumber by foliar sprays of phosphate and potassium salts Crop Protection 15:149-53

Rosenfeld, A; Collier, R. and Jayasinghe, C. (2006) Evaluation of module-sown companion plants as a method of controlling cabbage root fly. Paper presented at Joint Organic Congress, Odense, Denmark, May 30-31, 2006 http://orgprints.org/7141/

Sengonca, C., J. Kranz, and Blaeser, P. (2002) Attractiveness of three weed species to polyphagous predators and their influence on aphid populations in adjacent lettuce. Journal of Pest Science 75: 161-165.

Sievwright, H C; Sutton, G L and Rosenfeld, A (2006) Plants for predators - a participatory experiment. Poster presented at What can organic farming deliver? COR 2006, Heriot-Watt University, Edinburgh, 18-20 September 2006; Published in Atkinson, C; Ball, B; Davies, D H K; Rees, R; Russell, G; Stockdale, E A; Watson, C A; Walker, R and Younie, D, Eds. Aspects of Applied Biology 79, What will organic farming deliver? COR 2006, page pp. 121-124. http://orgprints.org/10202/

Solomon, M., Fitzgerald, J. and Jolly, R. (1999) Artifical refuges and flowering plants to enhance predator populations in orchards. IOBC/WPRS Bulletin 22:31-37

Speiser C. and Kistler (2002) Field tests with a molluscicide containing iron phosphate Crop Protection 21: 389-394

Speiser, Dr. Bernhard; Zaller, Dr. Johann G and Neudecker, A (2001) Size-specific susceptibility of the pest slugs Deroceras reticulatum and Arion lusitanicus to the nematode biocontrol agent *Phasmarhabditis hermaphrodita*. BioControl 46:311-320.

Sumption, P.D, (2008) Review of Published Information on Breeding and Trialling of Vegetable Varieties in Low Input (and Organic) Management Systems. A Desk Study. Unpublished, submitted to Defra as part of OF0375

Tamm, L.; Smit, A.B.; Hospers, M.; Janssens, S.R.M.; Buurma, J.S.; Molgaard, J.-P.; Laerke, P.E.; Hansen, H.H.; Hermans, A.; Boedker, L.; Bertrand, C.; Lambion, J.; Finckh, M.R.; Schüler, Chr.; Lammerts van Bueren, E.; Ruissen, T.; Nielsen, B.J.; Solberg, S.; Speiser, B.; Wolfe, M.S.; Phillips, S.; Wilcoxon, S.J. and Leifert, C. (2004) Assessment of the Socio-Economic Impact of Late Blight and State of the Art of Management in European Organic Potato Production Systems. FiBL Report. Research Institute of Organic Agriculture FiBL, Frick, Switzerland. http://www.ncl.ac.uk/tcoa/producers/research/blightmop/report4.html

US EPA (1998) Iron (Ferric) Phosphate (034903) Technical Document http://www.epa.gov/pesticides/biopesticides/ingredients/tech_docs/tech_034903.htm

Verkerk, R. (2001) Farmers' friends. Recognition and conservation of natural enemies of vegetable pests. Biology department, Imperial College of Science, Technology and Medicine, London.

West J.S.1; Pearson S.1; Hadley P.1; Wheldon A.E.2; Davis F.J.3; Gilbert A.3; Henbest R.G.C.4**:** (2000) Spectral filters for the control of Botrytis cinerea Annals of Applied Biology, 136:115-120

Widmer, T.L. and Abawi, G.S. (1998) Marketable yields of carrots in *Meloidogyne hapla*. Journal of Nematology 34:16-22

Zarb, J.; Ghorbani, R.; Juntharathep. P; Shotton, P; Santos, J.; Wilcockson, S.; Leifert, C.; Litterick, A. M; Bain, R. A. and Wolfe, M. (2002) Control strategies for late blight in organic potato production. Paper presented at UK Organic Research 2002 Conference, Aberystwyth, 26-28 March 2002; Published in Powell, Jane and et al., , Eds. *Proceedings of the UK*

Organic Research 2002 Conference, page pp. 221-222. Organic Centre Wales, Institute of Rural Studies, University of Wales Aberystwyth.

31.3.09