CAN POTATO PRODUCTION BE SUSTAINED IN LAND INFESTED WITH HIGH POPULATION DENSITIES OF THE POTATO CYST NEMATODE *GLOBODERA PALLIDA*?

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ABSTRACT

A field trial at Great Bolas, Shropshire, investigated the effect of oxamyl (Vydate 10G, Du Pont) on the control of the potato cyst nematode (PCN) *Globodera pallida*, and the yield of the partially resistant potato cultivar Santé. The trial was situated on a Bridgnorth series black sand soil with an initial *G. pallida* population density of 90 eggs/g of soil. Potato production would not usually be recommended on such highly infested land. In spite of the high initial population density of PCN, the trial produced acceptable ware yields of 40.8 t/ha from nematicide treated plots and 35.4 t/ha from untreated plots. Also, the overall *G. pallida* population density on the trial site decreased, which suggests that potato production that is profitable and sustainable can be obtained in highly infested land. The contribution of cultivar resistance, tolerance, nematicide and good husbandry are discussed in the context of integrated PCN management.

INTRODUCTION

The potato cyst nematodes *Globodera rostochiensis* and *G. pallida* are among the most difficult of crop pests to control in the UK. Granular nematicides such as oxamyl and aldicarb have been successful in controlling *G. rostochiensis* when used in conjunction with crop rotations and resistant cultivars. However, the integrated control of *G. pallida* has been less successful due to the lack of fully resistant cultivars and lower rates of natural population decline, making crop rotation less effective (Whitehead, 1993). These problems may have been exaggerated by the quota system which has effectively concentrated potato production on the most suitable land and thereby decreased the lengths of rotations. At present, the UK potato industry has to manage the *G. pallida* problem and a large number of producers are growing potatoes in land infested with high population densities of this species. Can this be sustained?

SUSTAINABLE POTATO PRODUCTION

Sustainable agriculture generally refers to production systems which rely on lower inputs and put more emphasis on long term and stable crop production with the least environmental damage, in contrast to focusing more on short term goals such as maximum yields (Bridge, 1995). Sustainable potato production in land infested with PCN requires the integration of control measures to achieve a constant or preferably declining pest population without causing a shift within mixed populations towards the more problematic *G. pallida* or to more virulent pathotypes. An additional essential component of sustainable production is that the crop is profitable to the grower.

FIELD TRIAL 1994

In 1994 a field trial at Great Bolas, Shropshire, demonstrated the effects of integrating several different control techniques on the management of the potato cyst nematode *G. pallida* and the yield of the potato cultivar Santé. Control techniques used were the partially resistant cultivar Santé, a granular nematicide and various agronomic practices designed to improve yield. The importance of each technique within a sustainable production system is discussed below.

Population estimation and determination of species

Accurate population estimation and determination of species is vital in order to quantify the pest burden in ground that is intended for potato production. This is important because the choice of control strategy for particular conditions may depend upon this information (Haydock & Evans, 1994). In this trial, the mean initial population densities were 80 and 96 eggs/g of soil for nematicide treated and untreated plots respectively (Table 1), and the population was determined to be pure *Globodera pallida* by isoelectric focusing (Fleming & Marks, 1983).

TABLE 1. Population measurements and yield

Nematicide (oxamyl) kg / ha	Pi(eggs/g of soil)	Pf (eggs/g of soil)	Pf/Pi	Ware yield (t/ha)
5.5	80	55	0.69	40.8
0	96	76	0.79	35.4

The initial population densities for the field trial were high and in most circumstances a commercial potato grower would be advised not to use such land for potato production, the upper threshold in current use being approximately 80 eggs/g of soil (T. Dawkins, pers.comm.). However, ware yields of 40.8 t/ha and 35.4 t/ha, whilst not being very high, are certainly profitable in most years. How was this achieved?

INTEGRATED CONTROL

The term integrated control in this instance refers to the combined use of several of the control methods that producers in the UK have available to manage PCN populations to provide a management package giving best possible control of the pest. The methods available in the UK are: legislative control, chemical control, plant resistance, crop rotation and possibly trap cropping. The aim is to make the most efficient use of control methods available and thereby maximise the control of the pest.

Legislative control

Legislative control of PCN is aimed at preventing their build up and spread. The legislation operates through UK Government orders, and the phytosanitary requirements of importing countries. Entry into the European community and acceptance of the PCN directive of 1969 (69/465 EEC) obliged the UK Parliament to pass an order making testing for PCN mandatory on land which is to grow potato seed for sale. The Potato Cyst Eelworm (Great Britain) Order 1973 adopted the measures required by the directive. The order established soil testing as the official method of determining whether land is free from infestation by PCN. The subsequent 1993 Plant Health (Great Britain) Order retains all the requirements of previous legislation. Movement of infested plant material between PCN sensitive countries is avoided by the phytosanitary requirements of the individual countries, which generally involve root inspection of growing potato crops and testing of soil taken from consignments ready for export. The import controls are very important because, for instance, South American populations of PCN are genetically more diverse than European populations and are able to overcome resistance conferred by genes currently incorporated in resistant cultivars in Europe (Franco & Evans, 1978); it is important that such pathotypes are not allowed to spread. Legislation, whilst not a direct method of control, may be the single most important factor in maintaining sustainable potato production in the UK. However, this legislation does not apply to home saved seed and localised spread of PCN on individual holdings is not prevented.

Chemical control

Chemical control of PCN in the UK uses two distinct types of nematicide, fumigant and non-fumigant. Fumigant nematicides, such as 1,3- dichloropropene mixture (Telone II, Dow Elanco), are used to kill eggs and juveniles in the soil. The chemical is injected into the soil in the autumn and the soil surface sealed either by rolling or by polyethylene sheeting to prevent the volatile nematicide escaping (Whitehead *et al.*, 1975a). Use of this type of nematicide is popular in the Netherlands but new legislation, which aims to reduce the amount of agrochemicals used in that country, has meant that methods for mapping the distribution of PCN infestations are being investigated in order to make more efficient use of smaller amounts of fumigant (Schomaker & Been, 1992). Non-fumigant or granular nematicides are more widely used than fumigants for chemical control of PCN in the UK. The oximecarbamates, oxamyl or aldicarb, are applied to the seedbed prior to planting. The action of these chemicals is as acetylcholinesterase inhibitors, effectively paralysing the nematodes and preventing them from locating host roots (Nelmes *et al.*, 1973). The extent to which a nematicide improves crop performance and limits nematode multiplication depends on the characteristics of the cultivar grown, such as its tolerance and whether or not it is resistant to the nematode population. Tolerant cultivars such as Cara show less response to nematicides in low to moderate infestations. Partially resistant cultivars such as Santé are generally less tolerant and need the protection of a nematicide to yield profitably (Gurr, 1987). Nematicides will continue to be required in sustainable potato production systems until more tolerant partially resistant cultivars are available. Fumigant nematicides do not require incorporation after injection into the soil as they diffuse through the soil pores as a gas but the non-fumigant granular nematicides require incorporation into the top 15cm of the soil to be effective (Whitehead *et al.*, 1975b). The use of stone and clod separators for incorporating nematicides may be reducing the efficiency of granular nematicides by incorporating the nematicides too deeply or by "layering" the chemical in the soil profile (Woods *et al.*, 1994).

Resistance and tolerance

Resistance to PCN in potato cultivars has been available since the 1960s, for example in the cultivar Maris Piper. The host plant is not resistant in terms defined by standard plant pathology, as it is still invaded and damaged by juveniles, and yield loss occurs. However, the capacity of the pest to reproduce successfully is reduced. Resistant cultivars limit the establishment of the feeding sites needed for female nematodes to develop, with the result that many juveniles become males. Potato cultivars with single major gene (H1) resistance to *G. rostochiensis* pathotypes Ro1 and Ro4 are available. Single major gene resistance to *G. pallida* is not available but partial resistance against *G. pallida* conferred by minor genes is available in commercial cultivars such as Santé. This cultivar was used in this field trial and successfully reduced the PCN population from 80 to 55 and 96 to 76 eggs/g of soil for oxamyl treated and untreated plots respectively (Table 1).The control provided by such cultivars is variable, depending on the virulence of the nematode populations to which they are exposed, but a decrease in the population is often obtained.

Tolerance is the ability of a plant to withstand attack by a pest without suffering undue damage (Trudgill, 1986). Resistance and tolerance are independent, but resistance may confer tolerance (Evans & Haydock, 1990). Tolerance exerts no selection pressure on the pest population but a risk with tolerant cultivars is that, without resistance, they will increase the population of the pest to levels where the tolerance is no longer able to cope with the pest burden. The tolerant cultivars Maris Piper and Cara (both of which are resistant to UK *G. rostochiensis*) have become popular over the past few years and it is possible that many fields have become heavily populated with *G. pallida* as a result. The tolerance of *G. pallida* partially resistant cultivars such as Santé could be enhanced by the use of good agronomic practice, so reducing the stress caused to the plant by factors that can be controlled. Irrigation, fertilisers, and good weed, aphid and disease control strategies may reduce stresses on the plant and allow good yields to be achieved in PCN infested land. Table 2 shows the inputs received by the field trial and explains their importance in improving the tolerance of the crop to PCN infestation.

TABLE 2. Agronomic inputs to field trial

Application	Comments
Liquid fertiliser - 1500 l/ha 10-8-11.5 preplanting. 984 l/ha 10-8-11.5 applied during planting	Application of fertiliser is important in terms of applied improving tolerance as the damaged root system of PCN infested plants is less efficient at nutrient uptake (Trudgill *et al.*, 1975b). Low soil indices of any of the major nutrients should be avoided as an infested crop with its reduced capacity for nutrient uptake will show yield reduction. Foliar applications of N, P and K may improve the tolerance of crops grown on moderately infested irrigated land.
Foliar fertiliser - four separate applications of foliar manganese at 1.25 l/ha. Four separate applications of foliar magnesium at 3.5 l/ha	Manganese and magnesium are both involved in photosynthesis. Magnesium levels in potato tissue decrease with increasing PCN infestation (Trudgill *etal.*, 1975a). The application of foliar magnesium and possibly manganese may help the potato plant to maintain its photosynthetic capability in moderately infested irrigated land.

TABLE 2. Continued

Application	Comments
Herbicides - contact and residual herbicides applied	The slower growth rates of PCN infested crops results in their reduced ability to compete with weed species.
Insecticides - dimethoate 0.62 l/ha (product rate) and cypermethrin 0.25 l/ha applied on two separate occasions	Stress from viruses transmitted by aphids may reduce the plants ability to tolerate the PCN burden, so ensuring that the plants are virus free and may improve the crops tolerance of PCN.
Fungicides - prophylactic blight spray programme	To reduce the risk of infection with potato blight (*Phytopthora infestans).*

In theory, careful choice of a resistant cultivar is important in maintaining sustainable potato production in PCN infested areas. However, in practice, market forces dictate which cultivars are grown. Several cultivars have been available over the past 10 years with varying degrees of resistance to *G. pallida,* such as Morag, Nadine & Santé, but only Nadine and Santé have been grown on any significant area. There is a need for both a concerted effort to promote cultivars with partial resistance to *G. pallida* and for more cultivars to promote. The latest, Valor, is promising but, unless the supermarkets can sell it or it has potential for processing, another useful cultivar may fail to fulfil its potential in PCN management.

Crop rotation

Crop rotation is a vital component of PCN management. PCN requires a solanaeceous host to reproduce and there are few if any weed species in the UK that act as good hosts to the pest (Whitehead, 1985). PCN declines naturally in the soil in the absence of a host as a small percentage of eggs will hatch without exposure to potato root diffusate. A decline rate of approximately 33% is expected for *G. rostochiensis* in UK soils but the rate of decline for *G. pallida* is generally slower at 15% per annum (Whitehead, 1993). This rate of decline could necessitate 10 year rotations when populations are large which is unacceptable for commercial growers. A crop rotation of 4-6 years, when used in conjunction with one or more of the other control methods, should provide a safe preplanting nematode population density (Whitehead, 1986). However, since the introduction of nematicides in the 1960s and the concentration of potato production on the most suitable land, rotations have become shorter and 1 in 3 rotations are not uncommon now.

Trap cropping

Trap cropping is a developing technique for reducing infestations on heavily infested land. By growing a vigorous cultivar such as Cara, a substantial hatch of eggs is induced. The potato crop is then lifted and destroyed when maximum hatch and invasion has occurred, but before any new cysts have matured. This technique has proved very successful, with populations of 40-465 eggs/g of soil being reduced by 75% or more in six weeks (Whitehead, 1994). However, if the crop is lifted too late an increase in PCN population density may occur. To improve chances of lifting the crop at the correct time, nematode development in the roots could be estimated by monitoring soil temperatures or observed directly by root examination. Trap cropping is still an experimental technique and should not be tried by growers without expert advice. With the introduction of set-aside in UK agriculture, the practice of trap cropping would seem a logical exploitation of the set-aside area in rotation. However, under current EC directives, the use of set-aside for trap cropping of PCN is prohibited.

ECONOMICS OF CONTROL

Sustainable potato production in the UK requires the system involved to be profitable to the grower both in monetary and agronomic terms. The cost of variable inputs and the gross margins for this trial for three price levels are shown in Tables 3 and 4 respectively.

TABLE 3. Costs of variable inputs to field trial

Input		Cost (£/ha)
Seed		600
Fertiliser		226
Foliar fertiliser		18
Nematicide		288
Sprays;	Herbicides	37
	Fungicides	31
	Aphicides	8
Others		6
Total	with oxamyl	1214
	without oxamyl	926

From the gross margins it can be seen that at a market price of £150-200/t the integrated management strategy is profitable and that nematicide treatment gives an increased gross margin. At a low market price of £50/t, the cost of a nematicide treatment reduces the gross margin to the extent that untreated plots gave a higher gross margin. However, at such low market prices, the gross margins of £825.79 and £843.44 for nematicide treated and untreated plots respectively would barely cover fixed costs, leaving very little profit. Gross margin analysis does not take into account the long term effects of nematicide use on the sustainability of potato production. The reduction in mean Pf/Pi from 0.79 to 0.69 by the use of a nematicide in this trial would increase the potential profitability of the next potato crop in the rotation by reducing the nematode population in the soil.

TABLE 4. Gross margins for field trial

		Market price of potatoes	
	£50/t	£150/t	£200/t
Cost of inputs oxamyl +	1214	1214	1214
(£/ha) oxamyl -	926	926	926
Value of output oxamyl +	2040	6120	8160
(£/ha) oxamyl -	1770	5310	7080
Gross Margin oxamyl +	826	4906	6946
(£/ha) oxamyl -	844	4384	6154

DISCUSSION

The production of potatoes in areas of high PCN population densities can still be profitable providing good agronomic management and an integrated approach to their management is followed. Jones (1969) demonstrated the effectiveness of combining several methods for the control of *G. rostochiensis*. Various combinations of rotation, growing resistant and susceptible cultivars and using a nematicide were studied. When a resistant cultivar was grown in nematicide treated ground on a 4 year rotation, a 99.9% kill of *G. rostochiensis* was observed. The integrated control of *G. pallida* has not been as successful due to the lack of fully resistant cultivars and the apparently longer hatching period of *G. pallida,* which it is believed may reduce the effectiveness of granular nematicides. The problem of lack of resistant cultivars is further compounded by the variability of the partial resistance, which can vary in effectiveness from field to field (Whitehead *et al.,* 1987). Hancock (1994) conducted a trial to study the management of *G. pallida* populations in intensively cropped potatoes. Results indicated that continuous production of potatoes on infested ground using a nematicide, soil fumigation and the partially resistant cultivar Santé was not economically viable or sustainable. Introducing a rotation of 1 in 2 improved the economic viability of the system, but to produce a sustainable cropping system, rotations of 1 in 4 would be required. Potato production on the trial site at Great Bolas 1994, can be seen as sustainable due to a decline in the overall pest population as a result of the management implemented. If commercial considerations would allow, increasing the rotation length from one in four would undoubtedly have further benefits. However, more work is needed in the area of integrated control of *G. pallida* if the species is to be managed as successfully as *G. rostochiensis.*

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INTEGRATED PEST MANAGEMENT OF APHIDS ON OUTDOOR LETTUCE CROPS

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ABSTRACT

A series of field and laboratory experiments were done at different centres to investigate various components of integrated pest management of aphid pests of lettuce. The study concentrated on the four main species of aphids infesting crops in Britain:- the currant-lettuce aphid, *Nasonovia ribisnigri*, the lettuce root aphid, *Pemphigus bursarius*, the peach-potato aphid, *Myzus persicae*, and the potato aphid, *Macrosiphum euphorbiae.* Immigration of alate aphids to lettuce was monitored weekly between May and October in Warwickshire, Lancashire, Lincolnshire and Kent with water traps and aphid population development was monitored on lettuce crops, cv. `Saladin' planted in succession during the season. Aphid species were identified and counted and a preliminary model was devised for *P. bursarius* which could be used to predict aphid immigration. The performance of several novel insecticides was determined in field experiments in Lancashire. Three of these insecticides controlled aphids as effectively as the approved products pirimicarb and demeton-S-methyl. The role of host plant resistance and two semiochemicals in limiting crop colonisation were investigated in a field experiment at HRI, Wellesbourne. Four lettuce varieties possessing different combinations of resistance to the various aphid pests performed as predicted, but the semiochemical treatments were not significantly different from the untreated plots. The entomopathogenic fungus, *Metarhizium anisopliae,* which is a pathogen of *P. bursarius,* was shown to kill aphids in a field experiment.

INTRODUCTION

Aphids are the principal pests of lettuce grown outdoors. They have the potential to destroy the crop or render it unmarketable. Crops of iceberg varieties, which occupy more than 60% of the area of lettuce grown, are attacked by two key species, the lettuce root aphid, *Pemphigus bursarius,* and the currant-lettuce aphid, *Nasonovia ribisnigri.* Two further species which cause less direct damage but can transmit viruses to the crop are the potato aphid, *Macrosiphum euphorbiae*, and the peach-potato aphid, *Myzus persicae.* Lettuce crops are planted sequentially throughout the spring and summer and currently aphid control relies on the routine and frequent use of insecticides with limited regard for the life-cycle of the pest. Individual crops may receive up to six applications of insecticide. The reduction of these inputs to limit insecticide usage and make the industry more competitive relates specifically to current MAFF policy. However, this can only be done if quality is not reduced.

Pemphigus bursarius feeds on the roots of lettuce and may kill plants, particularly in dry seasons. *Nasonovia ribisnigri* attacks the foliage, penetrating to the heart of the plant, making it unmarketable. Once crops have been colonised, these species occupy parts of the plant that are extremely difficult to reach with conventional insecticides.

Both aphid species overwinter as eggs on a woody host plant, *P. bursarius* on poplar and *N. ribisnigri* on currants. In spring, eggs hatch and after two to three generations, winged aphids fly to colonise lettuce crops. In the case of *N. ribisnigri*, further winged aphids may develop on lettuce in the summer and disperse to new lettuce crops. There is already considerable knowledge of the biology of *P. bursarius* on its winter host (Dunn, 1959) and of the timing of its migration to lettuce, but equivalent information for *N. ribisnigri* is inadequate. The timing of these key events in the biology of the pest are vital in the targeting of appropriate control strategies to limit or prevent crop colonisation.

The process of crop colonisation is a key stage at which the development of pest epidemics on lettuce can be limited. Lettuce genotypes exhibiting resistance to one or both of these aphid species are available, through a commercial breeding company, in advanced breeding lines, following identification of some of the original germplasm through MAFF funding at HRI. The use of resistant plant material limits crop colonisation. The mechanisms of resistance have been shown to be based on single genes (Eenink & Dieleman, 1983; Ellis *et al.*, 1994), and so aphid strains may be able to overcome this resistance rapidly. The effectiveness of the resistant material will have a longer life if deployed for use only when necessary rather than throughout the cropping season, and when combined with other control strategies.

Aphid behaviour, particularly host finding, can be manipulated to limit crop colonisation further. It has already been shown at IACR Rothamsted that winged cereal aphids respond to host plant volatiles (semio-chemicals), and that appropriate volatiles can be used to "confuse" an aphid into mis-identifying its preferred host plant, so limiting colonisation (Pickett *et al.,* 1992).

Despite all efforts to prevent aphids landing on crops, limited colonisation will inevitably occur. Novel products, with new modes of action, have recently been released by pesticide companies, but do not yet have approval for use on lettuce. In addition, an isolate of the aphid pathogenic fungus, *Metarhizium anisopliae*, is currently under development in a MAFF funded programme at HRI for control of *P. bursarius*. A different isolate of *M. anisopliae*, that is not pathogenic to *P. bursarius*, has already been registered in the UK for the control of other pests. The appropriateness of these different products within integrated pest management (IPM) programmes has yet to be quantified.

The purpose of the project is to develop an integrated strategy for the control of aphids on outdoor lettuce through the integration of novel and existing control methods targeted at key stages in the life cycle of the pest species using accurate pest forecasting. The system developed would provide a strategy for aphid control which would lead to sustainable lettuce production and sustainable control methodologies.

MATERIALS AND METHODS

Monitoring of immigration of alate aphids and their population development

Crop colonisation and aphid population development were monitored by:-

Trapping winged aphids.

Yellow water traps fitted with vertical yellow baffles were placed in the perimeter of lettuce fields at HRI (Wellesbourne), Warwickshire, HRI (Kirton), Lincolnshire, in Kent and Burscough, Lancashire. Aphid samples were collected twice a week (May to October inclusive) and the aphids identified and counted.

Sampling `Saladin' lettuce plants.

Five sequential-sowings of the iceberg lettuce cv. `Saladin' were made at HRI (W), HRI (K), and three in Burscough. The plants were sampled twice a week throughout the season (May to October inclusive). Aphids on the foliage were identified and counted. In addition, sampled plants were lifted and their root system scored for *P.bursarius* infestation.

Novel insecticides

Field experiments were done on growers holdings in Lancashire in 1994 to compare the performance of three novel insecticides with the currently-approved products pirimicarb and demeton-S-methyl. Both seed-treatments and sprays were compared and plants sampled twice following application.

Semio-chemicals and resistant varieties

In a large field experiment at HRI, Wellesbourne in 1994 the effect of host plant resistance and of two semio-chemicals, methyl salicylate (an extract from willows) and butyl isothiocyanate (an extract from cruciferous crops) on aphid colonisation and development was compared. Untreated plots were also included in this experiment. Semio-chemicals were released from sachets which were placed in the crop on two occasions during the season. Plants were sampled on 7 occasions to record aphid abundance as well as root aphid damage.

Biological control of aphids

The fungus, *M. anisopliae*, obtained from a laboratory culture was incorporated in peat blocks at the rate of 10^7 and 10^8 spores per ml to inoculate `Saladin' lettuce plants raised in peat blocks. A wetting agent was used as a control treatment. Roots were sampled at the end of the season to determine the effects of the fungus on a severe infestation of *P. bursarius* which had colonised the crop.

RESULTS

<u>Monitoring of immigration of alate aphids and their population development</u>

The data from water traps and monitoring plots were analysed and graphs illustrating seasonal patterns of activity produced. Examples of two of these give some indication of aphid numbers and their phenology (Figures 1 & 2).

Thus, water trap samples indicated a single period of immigration of alate *P. bursarius* from poplar to lettuce in late June/early July. (Figure 1).

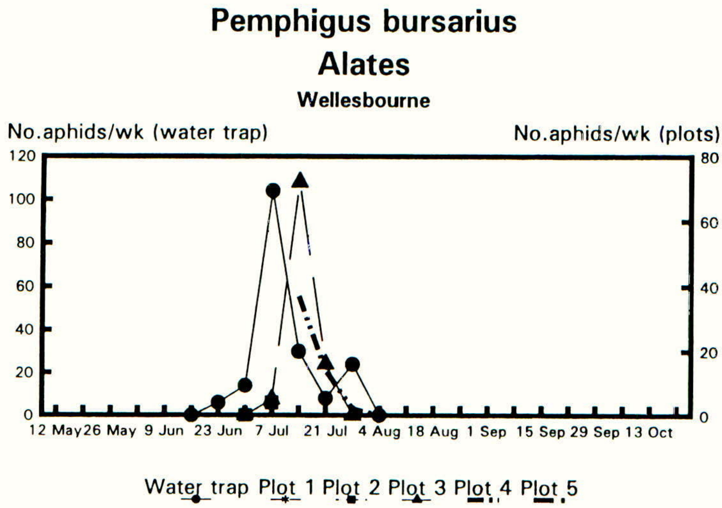

FIGURE 1. The immigration of *P bursarius* to lettuce, as indicated by water trap samples, and samples from plots of lettuce planted sequentially, at HRI Wellesbourne, 1994.

The picture for *N. ribisnigri* was more complicated (Figure 2).

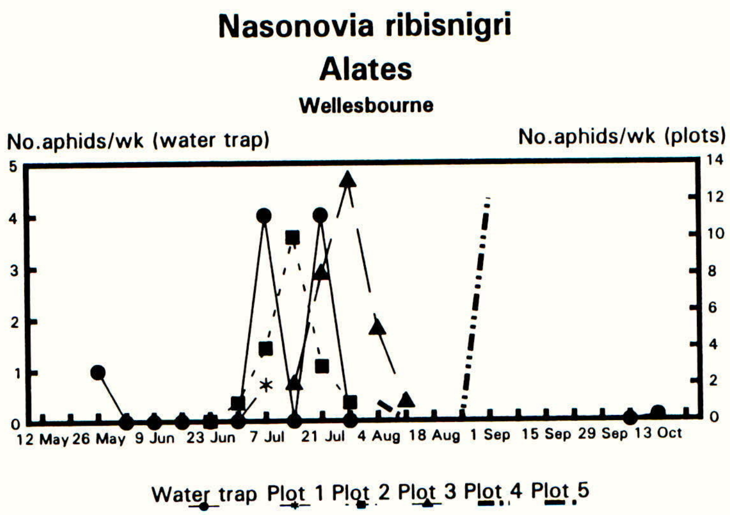

FIGURE 2. The immigration of *N. ribisnigri* to lettuce as indicated by water trap samples and samples from plots of lettuce planted sequentially, at HRI Wellesbourne, 1994.

Immigration of *N. ribisnigri* from overwintering sites on *Ribes* species occurred at almost exactly the same time as *P. bursarius* but further immigration was recorded in July and again in September.

The other two aphids species, *M. euphorbiae* and *M. persicae,* colonised lettuce plants earlier in the season but their numbers declined rapidly in late July as the numbers of natural enemies increased in the crop. These two species are the most important vectors of virus diseases to the lettuce crop and so their activity must also be forecast accurately.

Novel insecticides

The results clearly showed that three of the novel insecticides have considerable potential to control the aphids on lettuce foliage (Figure 3). There is a need to collect further data, particularly that required for approval for any new compounds for use on lettuce.

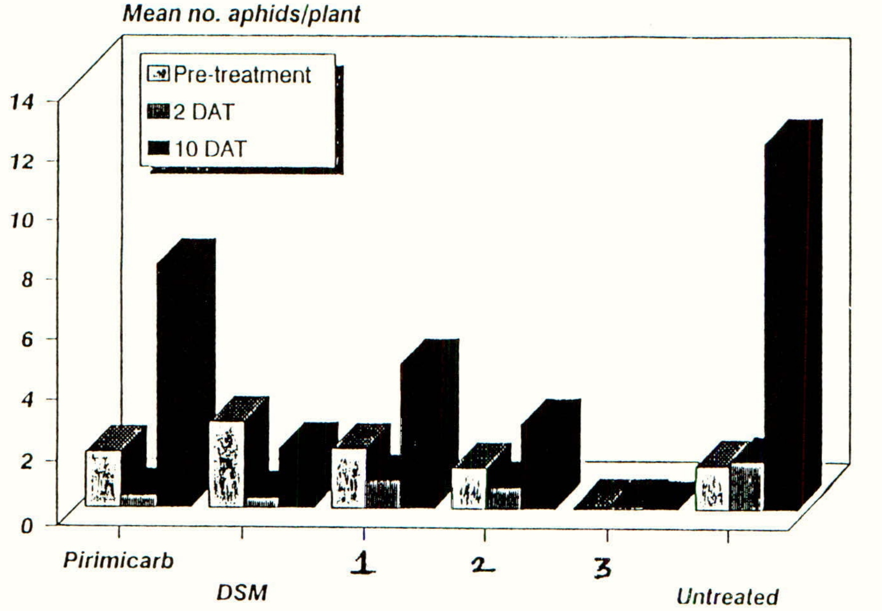

FIGURE 3. The efficacy of the commercial standard insecticides, pirimicarb and demeton-S-methyl, as compared to three coded products to control aphids on lettuce foliage at Gregson's Bridge, Lancashire. (DAT = days after treatment).

Semio-chemicals and resistant varieties

The crop was colonised by large numbers of aphids. The experiment provided valuable information on the performance of the different lettuce varieties. Thus `Saladin' was highly susceptible to all aphid species, `Beatrice' possessed total resistance to root aphid but was the most heavily colonised variety by foliage species. `Great Lakes' was susceptible to foliage species but partially resistant to root aphid whilst `Iceberg' possessed high levels of resistance to root aphid and partial resistance to foliage species. The results of releasing semio-chemicals into the plots was less clear. Overall, methyl salicylate-treated plots were the least colonised but there were interactions between variety and chemical treatment so that on `Beatrice' both semio-chemicals reduced colonisation whilst this effect was not evident on the other lettuce varieties.

Biological control of aphids

The control plants became infected as well as the inoculated lettuce and so scoring became complicated and difficult. More work is needed to develop the techniques in handling the pathogen and scoring the performance of the inocula.

DISCUSSION

It should be possible to predict accurately the timing of this migration of *P. bursarius* from poplar trees in the future. Winged *P. bursarius* leaving the lettuce crop all fly back to poplar. However, limited spread within fields can occur as young wingless individuals (crawlers) move from plant to plant or row to row and several weed species, closely related to lettuce, may serve as resevoirs of root aphid. This species is also known to overwinter in fields and colonise any lettuce crops planted out in spring or summer. The conditions governing this ability to overwinter and the degree of infestation which results need to be investigated.

N. ribisnigri activity in the middle of the season indicated movement between lettuce crops whilst the peak at the end of the season suggested the production of winged individuals which would be flying back to *Ribes*. In Europe and parts of the UK, *N.ribisnigri* is the most prevalent aphid on lettuce and so it is vitally important to be able to predict accurately its activity.

It is clearly sensible to utilise whatever sources of host resistance exist provided that the plant material is acceptable to the grower and consumer. At present no single iceberg variety of lettuce possesses resistance to all aphid species. However, seed companies and HRI(W) are developing lettuce breeding lines which possess resistance to the most important species of aphid. Varieties bred from these lines should reduce the growers' dependence on insecticides at times of the year predicted from the forecasts.

Further work is needed on both semio-chemicals and biological control agents of aphid pests before these approaches can be integrated with resistant varieties, cultural and chemical control methods.

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