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SCOPE AND OBJECTIVE

There is increasing pressure on growers of field brassica crops to reduce pesticide use by adopting systems of supervised control. Systems of supervised control for foliar pests of Brussels sprouts and calabrese crops have been tested with some success in experimental field plots in the UK. However, commercial growers question their economic viability, particularly in situations where there is a 'nil tolerance' for pest damage. Growers are concerned about 1) the time spent inspecting crops, 2) the risks attached to omitting sprays and 3) the costs of implementing such systems. The aim of the project is to develop a robust cost-effective system for cabbage aphid and caterpillar control. This will be based on a practical crop-walking scheme designed to increase sampling precision without increasing inputs markedly. The timing and frequency of crop walking will be determined using monitoring and forecasts of aphid and caterpillar development.

BENEFITS

1. Growers will benefit from a detailed evaluation of the "supervised" control technique they are being encouraged to adopt by supermarkets.

2. The project will demonstrate how pest assessment, based on crop walking, should be carried out commercially.

3. Growers will benefit from the provision of a robust system with known levels of accuracy, for assessing cabbage aphid and caterpillar infestations in *Brassica* crops.

ACTION POINTS FOR GROWERS

Development of a practical supervised pest control protocol

The increased pressure on growers to adopt systems of supervised pest control, and the need to collect data to justify decisions to treat crops, raises questions about how best to collect such data to allow reliable decisions to be made. Work within this project (and related projects) has provided answers to some of these questions, and for seven identified areas of choice, the recommended choices are described below.

The seven areas are:

1. Where to sample?
2. When to sample?
3. What to sample?
4. How many plants to sample?
5. How to summarise the collected data to make decisions?
6. What treatment thresholds to use?
7. What risks of making incorrect decisions to allow?

Many of the options and choices within these areas are inter-related. Some of these inter-relationships are highlighted in the Discussion.

1. Where to sample?

Growers can obtain an estimate of the worst scenario within a field by sampling plants close to the edges. However, the sample will be representative only if they sample plants from all edges, and from a considerable length of each edge. The recommended approach is therefore to sample plants from a number of locations close to the field edges.

Where sufficiently large samples are assessed along each edge, a separate decision can be made for each edge, and the overall decision based on the worst infested edge. Where a grower decides to treat parts of the field differently (e.g. centre and areas near to each edge), a representative sample needs to collected from each of these areas. If a sufficiently large sample is obtained only by combining the samples from all edges, then the treatment decision must be based on the combined sample. This is straightforward when a fixed-size sample approach is used, but an, as yet, unsolved problem when using a sequential sampling approach.

In devising a joint strategy for sampling crops for caterpillar and aphid infestations, a scheme based on the spatial distribution of caterpillars should be used. The current recommendation is to sample plants that are separated by at least 10 plants.

2. When to sample?

Where forecast models are available these should be used to predict the start of pest activity, and hence the start of crop sampling. Where forecast models are not available, a set of monitoring plants could be used to identify the start of pest activity (and hence the start of crop sampling). Alternatively, sampling could commence immediately after planting.

A minimum re-sampling interval following insecticide applications should be based on the efficacy and persistence of the insecticide used. This may vary depending on weather conditions. The re-sampling interval also depends on the rate of pest development and should be shorter when temperatures are high or when there is an increased risk of new infestation. Assuming that a simple 'spray – no decision – no spray' decision making system is used, the same re-sampling intervals are recommended when the 'no spray' decision is reached, and re-sampling intervals half the length when a 'no decision' is reached.

3. What to sample?

Individual plants should be considered as the sampling unit. These should be selected from within the sampling area, in a systematic manner, using the inter-plant spacing specified above. For example, this could be on a 'grid' with distances between sampling plants determined by fixed numbers of paces along and between rows.

The presence or absence of each pest species on each sampled plant should be recorded.

4. How many plants to sample?

In general, the larger the sample size the more confidence the grower can have in his decision. However, where relatively high treatment thresholds are being used, a smaller sample size can be used with little loss of precision or confidence. If a sequential sampling system is used, then the maximum sample size can be larger than that for an equivalent fixed-size sampling system as the average sample size will be considerably below the maximum.

The choice of sample size is influenced greatly by decisions on thresholds, the risk of making an incorrect decision, the decision-making scheme used, and how the crop is to be treated. The sample size can be selected by comparing the probabilities of reaching each outcome, and the average sample size, for a range of infestation levels around the threshold. The choice of sample size remains a compromise between the costs of obtaining additional information (increasing the sample size), and the risks associated with reaching incorrect decisions or being unable to reach a 'positive' decision.

5. The decision making process

Ideally a sequential sampling approach should be adopted; selecting an appropriate chart based on growers' requirements. One constraint to using this approach at present is that each area of a field would need to be sampled separately, with a final treatment decision based on the "worst" edge scenario. Some training of assessors would be required to implement such schemes practically.

Fixed-size sampling schemes may provide a simpler alternative, although with the disadvantage of requiring larger sample sizes when the infestation level is substantially different from the threshold. For both approaches, some further work is required to develop a system to generate customised decision-making charts rapidly.

6. Treatment thresholds

In the absence of any better information, the treatment thresholds used in the small plot trials during this project should be used. For aphids, where seed treatment is available, higher treatment thresholds (20% or 10%) can be used during the first ten weeks after planting. Where a 5% treatment threshold is used, however, a sample size larger than that used in this project is recommended, to allow a 'no treatment' decision to be reached if appropriate.

The concept of 'nil tolerance' does not fit easily into a sample-based system, since all plants in a field would need to be sampled to be sure that no plants were infested. Relatively large samples are required for supervised control at low thresholds, to estimate infestation levels with sufficient precision. Where an inadequate sample is used, reliable decisions can only be made when the infestation is considerably larger than the threshold. If the infestation size is close to or less than the threshold then it may not be possible to make a confident decision, either to spray or not to spray.

7. Risks of incorrect decisions

Three types of risk are associated with selecting a sampling/decision-making scheme. The first two are provided usually as the parameters of the scheme, and can be thought of as the "grower's risk" (the risk of not spraying when the true level of infestation is above the threshold) and the "consumer's risk" (the risk of spraying when the true level of infestation is below the threshold). The third type of risk is influenced heavily by the choice of sample size, and is the risk of not gathering sufficient information to be able to make a confident decision either way.

The properties of sampling schemes should be selected in conjunction with decisions about sample size and the decision-making process, but growers will probably wish to keep the "grower's risk" relatively low, whilst allowing the "consumer's risk" to be a bit higher. The values selected should be dependent on the associated "costs" of incorrect decisions.

Aphid and caterpillar control

- There was a clear relationship between the numbers of sprays applied to control aphids (OP/pirimicarb/pyrethroid) and the effectiveness of the spray programme when compared with the untreated control plots. Extrapolation from the fitted equation indicated that using this range of insecticides, approximately 18 sprays would have to be applied to a crop to achieve 90% control. Thus on a crop where 50% buttons would be infested in the absence of insecticide treatment, 18 sprays would be expected to leave 5% of buttons infested at harvest. Obviously, in years when infestations are low, acceptable levels of control could be achieved with fewer sprays. However, in years of heavy infestation it would not be possible to achieve acceptable levels of control without the application of large numbers of sprays.
- The relationship between the numbers of sprays and percent aphid control shows the value of a supervised system. If sprays were applied routinely, then in years of light infestation, some sprays would be applied unnecessarily. Alternatively, more sprays might be required in years of heavy infestation.
- Late immigration of winged aphids is one of the factors that appear to reduce the size of the infestation and consequently the numbers of sprays applied. Sprays applied before aphids have established in the crop have no effect on infestation levels at harvest. The timing of immigration can be forecast from temperature data, although such forecasts have not been validated extensively. In addition, careful crop monitoring on a local or regional basis should indicate when aphids arrive.
- Supervised systems are very effective for caterpillar control. Infestations have been light over the last two years and few sprays have been applied to the supervised plots, with no marked loss of control. In contrast, infestations were particularly high in 1996, with a consequent increase in the number of insecticides applied to control caterpillars in supervised plots (LINK Project FV 163).
- Effective caterpillar control can be obtained by targeting insecticide treatments only at the periods when caterpillars are present in the crop. The timing of immigration can be forecast from pheromone trap catches and temperature data; forecasts are being refined and validated in HDC Project FV 163a. In addition, careful crop monitoring on a local or regional basis should identify when caterpillars arrive.

SCIENCE SECTION

INTRODUCTION

There is increasing pressure on growers of field brassica crops to reduce pesticide use by adopting systems of supervised control. For example, the NFU-Retailer Integrated Crop Management (ICM) protocols for brassica crops indicate 1) that control measures should be applied only when the pest is present, 2) that routine applications of insecticides at fixed time intervals are not desirable and 3) that crops should be inspected regularly to determine whether they actually need to be sprayed. The protocols also indicate that where tolerance levels exist, they should be used.

Systems of supervised control for foliar pests of Brussels sprouts and calabrese crops have been tested with some success in experimental field plots in the UK. However, commercial growers question their economic viability, particularly in situations where there is a 'nil tolerance' for pest damage. Growers are concerned about 1) the time spent inspecting crops, 2) the risks attached to omitting sprays and 3) the costs of implementing such systems. The aim of the project was to develop a robust cost-effective system for cabbage aphid control. This is based on a practical crop-walking scheme designed to increase sampling precision without increasing inputs markedly. The timing and frequency of crop walking is determined using information about insecticide efficacy and aphid development.

The project evaluated a practical crop-walking scheme for assessing cabbage aphid infestations. It also evaluated the robustness of tolerance levels and the overall viability of the system. The experimental work was done in Brussels sprouts, as this crop is exposed to pest attack for several months and often receives many applications of insecticide.

Systems of supervised control for foliar pests of brassica crops have been developed in North America, Northern Europe and particularly in the Netherlands (Ellis *et al.* 1988; Hommes *et al.,* 1988, Theunissen, 1984; 1988; 1991; Theunissen & Den Ouden, 1985). Evaluation of such systems in small plot trials in the UK, with MAFF (Projects F05D & PI0321) and HDC (Project FV 119) funding (Blood Smyth *et al.*, 1992; 1994; Emmett, 1992; Paterson *et al.*, 1994)), showed that the numbers of insecticide sprays applied against cabbage aphid could often be reduced considerably without reducing the levels of aphid control. However, although the sampling system was extremely accurate it was designed primarily as an experimental tool for testing the accuracy of spray thresholds and was not disseminated to growers because it was too time consuming for field-scale decision making. The levels of control achieved also depended on the insecticide used.

MAFF-funded work (HH1910SFV) done during 1994-96 at HRI Kirton and HRI Stockbridge House was directed towards revising the current tolerance levels for the cabbage aphid by including information on 1) aphid phenology, 2) the growth stage of the plant, 3) the insecticide applied. The rapid increase in aphid numbers in early summer is usually followed by a natural 'crash' in the aphid population during late July-early August caused by predation, parasitism and a naturally-occurring fungus disease. Insecticide treatments applied during this period may often be unnecessary. Later in the summer, aphid numbers usually increase again; the rate of increase being determined by weather conditions. At this stage, the timing of insecticide treatments may be critical. With HDC support, a preliminary system for forecasting cabbage aphid attacks was developed at HRI Kirton (FV 121). The forecast uses air temperature, rainfall and relative humidity to predict periods when aphid numbers are increasing or decreasing. The growth stage of the plant is also important since plants may be able to tolerate higher levels of aphid attack at certain growth stages without suffering loss of yield or quality at harvest. Particular insecticides may provide higher levels of aphid control at certain times.

In parallel with the work on aphid control (and also in MAFF Project HH1910SFV), the spatial distribution of cabbage aphids within crops has been investigated. The use of tolerance levels to make spray decisions depends on having reliable estimates of the levels of pest infestation in individual crops. All of the previous MAFF and HDC funded work has been done in plot trials where the numbers of plants sampled on each occasion represented a large proportion of the plants in the plot (usually 1-5% in plots of 1,000 - 6,000 plants).

In general, the largest numbers of aphids are found at the edges of the crop with a gradual decrease in numbers away from the edges. Headlands may also act as 'edges'. The objective of this work has been to identify those areas of the crop which are most susceptible to aphid attack and to relate overall levels of infestation to the numbers of aphids found there. From April 1996, MAFF has funded an Open Competition project on cabbage aphid (HH1923TFV), lead by Dr Bill Parker from ADAS Wolverhampton. Geographical Information Systems are being used to investigate aphid distributions more fully and this information will be incorporated into the crop walking system being developed within the current HDC-funded project, as it becomes available. The aim of this project is to develop a sampling scheme, which will enable growers to assess pest infestations in their crops as consistently as possible, and with known levels of accuracy, so that they can use tolerance levels to make reliable spray decisions.

MAFF and HDC have funded related work on caterpillar pests (LK0426, FV 163) which was done at HRI Kirton, HRI Wellesbourne, HRI Stockbridge House and ADAS Arthur Rickwood. It is essential that the systems developed for aphids and caterpillars are compatible and this will be a key objective of the work in the current project.

EXPERIMENTAL

Development of a practical crop walking scheme

1996 & 1997

Between 18 July and 23 October 1996, 20 commercial crops of brassicas (11,000 plants) were sampled intensively to determine the numbers of plants infested with cabbage aphids. Fields were located with the co-operation of OLGA and suitable crops were identified by scouting at regular intervals; the aim being to sample crops with a range of levels of aphid infestation. Normally, fields were sampled prior to spraying.

Plants were sampled from nine locations within each field (edges, corners, middle). These locations were determined from work on the distribution of cabbage aphids done previously with MAFF funding.

Between 1 August and 29 October 1997, a further 16 commercial *Brassica* crops (5,300 plants) were sampled intensively. Fields were located with the co-operation of the OLGA and UNIVEG. Plants were sampled from five locations (edges, middle) within each field. These locations were determined from information collected in 1996.

Records taken

The numbers of winged and single wingless cabbage aphids and the numbers and size of cabbage aphid colonies on each plant were recorded. For completeness, the numbers of mummified aphids parasitised by the wasp *Diaeretiella rapae* and the numbers of aphid predators (ladybirds, hover-flies, lacewings) were recorded also.

Although experimentally it is important to record the numbers of aphids on each plant to obtain an estimate of the overall size of the pest population, practically it is easier to base crop walking on the presence or absence of aphids on each plant and to make decisions based on the proportion of plants infested. Within this report, aphid infestation levels are described only in terms of the proportion of plants infested.

Field information

A plan was drawn of each field to record its approximate dimensions and orientation (N, S, E, W), the crop and the height of the field boundaries. The crops were cauliflower, calabrese or Brussels sprouts. A few fields were planted with both calabrese and cauliflower. Photographs were taken of the field boundaries.

Data analysis

The data for each field were entered onto spreadsheets and the numbers of plants infested with winged aphids, single wingless aphids and aphid colonies in each area of the crop were calculated.

<u>Distribution of cabbage aphids in commercial crops</u>

More than 16,000 plants were examined in 1996 and 1997 in 36 fields. An average of 5.6% plants was infested with cabbage aphids in 1996 and 7.7% of plants in 1997. An average of 11% of plants was infested with peach-potato aphids in 1997. The results are presented in detail in the Annual Reports for 1996-1997 and 1997-98.

Corners and edges

On average, the percentages of plants infested at the edges and corners of fields were similar (6.1 and 6.9% respectively in 1996).

Edges vs middle

The data collected in 1997 were combined with those collected in 1996. When the mean percentage of plants infested on the edges was compared with the percentage infested in the middle of the crop, more plants were infested on the edges than in the middle in 26/36 (72%) of the fields. When the most heavily infested edge was compared with the middle of the crop, this increased to 34/36 (94%) of fields.

Variation between edges and corners
There were often considerable differences between the edges and the corners of an individual field in the percentage of plants infested. For example, in one crop, planted completely with cauliflower, 8% of plants on Edge 2 were infested and 32% on Edge 4. In other crops, the aphids were distributed more evenly.

The orientation (N, S, E, W) of the most heavily infested edge(s) in each field was determined (fields with two equally infested edges were scored as 0.5 for each edge). No pronounced trend was evident, although more aphids were found along the SW/NE axis.

Similarly, the heights of the field boundaries were compared with the percentage of plants infested and again no pronounced trends were evident. However, most of the field boundaries were low and few of the fields were bounded by very tall hedges or trees; which may be important factors in determining aphid distribution in more sheltered fields. Aphid distribution also did not appear to be affected consistently by crop species in the fields that were planted with more than one crop.

Simulation of crop sampling strategies
A program was developed in the computer package MATLAB to simulate a range of crop sampling strategies using the data set collected from commercial fields.

Options that can be selected within the program include:

1) Crop
The data sets collected in 1996 and 1997 are available, covering a range of brassica crops sampled at different times of year.

3) Areas of the field to be sampled
Data are available on pest infestation levels in the 4 corners of the field (1996 only), along the 4 edges of the field, and from the middle of the field. Any combination of areas can be selected, and the number of edges or corners to be sampled must also be chosen where appropriate. Presently, where multiple corners or edges are selected, these are chosen at random within each simulation run. In a future version of the program it would be possible to select specific corners or edges.

4) Sample size
Limits on the possible sample size are set according to the areas selected. Having selected the overall sample size it is possible to sample equally from each of the selected areas, or according to a range of pre-defined ratios (e.g. two thirds of the samples from one area and one third from another area).

5) How plants are chosen within the sampling areas
Plants can either be sampled completely at random, along pre-defined transects, or from clumps. The same approach is used in each of the sampling areas.

6) Number of replicate simulations

A default setting of 100 is provided - the more simulations, the longer it takes to produce results, but the more accurate the picture of potential variability.

The simulation program allows an infinite number of sampling strategies to be tested and can be used to indicate trends associated with, for example, changes in sample size or in sampling area.

Sample size

The effect of sample size on the coefficient of variation (CV) was studied by making repeated simulations. The CV is the ratio of the standard deviation to the mean and if, for example, the CV is 5% of the mean, 95% of estimates made will be within approximately $\pm$ 10% of the true infestation level; although this will also be influenced by the absolute size of the infestation.

As the sample size increased, repeated estimates of the percent plants infested became more reproducible and the CV was reduced. The CV was also affected considerably by the overall level of aphid infestation within the crop and when aphid numbers were high, the sampling strategy was reproducible (low CV) even at quite low sample sizes.

Sampling areas

Choice of sampling area(s) will also determine the variability of the estimate of the population. If samples are taken only from the middle of the crop then this will on average indicate a level of infestation that is lower than that on the field edges. If only one of the edges or corners is sampled then this estimate may not necessarily indicate the worst scenario. In general the CV was reduced and estimates became more reproducible as more edges or corners of the crop were sampled.

Current methods of crop walking

When crop walking, growers are prepared to spend at least 15-20 minutes in individual crops and will look at a number of plants (possibly 20-30), although usually not as thoroughly as for experimental purposes. They generally look at several plants on the edge of the crop, usually in the edge nearest to the field entrance, and then walk a transect into the crop stopping to examine plants at intervals. They do not record what they find on individual plants but tend to make their decisions based on experience and a 'gut feeling'. Many of the growers keep records of their general impressions of the crop to support spray decisions.

One of the greatest problems for growers is having enough time to walk all the crops at regular intervals and a system which would enable them to group fields with respect to crop walking information would be very useful.

Comparison of grower practice with simulations

On 8 September 1997, a group of growers from OLGA visited a commercial calabrese crop near Friskney in south Lincolnshire and 21 members of the group walked the crop to determine the proportion of plants infested with aphids and with caterpillars. Each member of the group examined a sample of 25 plants of their choice. The crop had been sampled earlier in the day by a team of scouts from HRI Kirton who obtained an estimate of the overall size of the infestation. The data were collated in the field for discussion with the group and compared subsequently with MATLAB simulations, using similar aphid and caterpillar infestation levels and a sample size of 25.

Aphid numbers were extremely low in the target crop, with an average of 5% of plants infested with either cabbage aphids or peach-potato aphids. However, 26% of plants were infested with caterpillars. Sampling by the 21 growers was compared with simulations based on similar levels of infestation. Although the growers' findings were broadly in line with the simulation, they were more variable and more growers than expected found no pests at all.

1998

The aim of the third year's work (1998) was to sample intensively small areas within commercial crops to obtain additional data on the spatial distribution of aphids. This was to confirm some of the conclusions drawn previously using more extensive sampling and to ensure that sampling for aphids and caterpillars could be incorporated into a single system. The spatial distribution of caterpillars was investigated in LINK Project FV 163.

Five commercial crops were sampled between 11 and 26 August 1998. Fields were located with the co-operation of the OLGA and suitable crops were identified by scouting a large number of brassica crops, the aim being to sample fields with a range of levels of aphid infestation. Infestation levels ranged from 0.2 – 3.5 aphid colonies per plant. In each crop, every plant in a block of 400 plants (10 rows x 40 plants long) was examined, starting from one edge of the crop.

Assessment of spatial patterns of infested plants

In the previous LINK project (FV 163), two approaches were developed to determine whether or not caterpillar infested plants were likely to occur near to other caterpillar infested plants, i.e. whether or not infested plants occurred in clusters. The results of these analyses were then used to determine the minimum distance between sampling locations in an adaptive sampling scheme.

The same approaches were used in this project to assess the spatial patterns of aphid infested plants. If infested plants do occur in clusters, it is important to avoid examining plants from the same cluster, since these observations may not be of independent infestation events. By selecting an inter-plant distance that avoids sampling the same cluster when the overall infestation level is low, it will still be possible to estimate high infestation levels. However, the probabilities of either overestimating the infestation level (by observing the same cluster more than once) or of underestimating the infestation level (by failing to observe clusters when the sampling area is too small) will be reduced.

Approach 1 – Black-White Join-Count Statistic

This approach is based on counting the number of times an infested plant is the neighbour of a non-infested plant. The identification of a first neighbour (adjacent plant) can be extended to second neighbours (one intermediate plant), third neighbours (two intermediate plants), and so on. Counts of neighbouring plants in different states (infested and non-infested), for each type of neighbour, can then be compared with the expected count if the distribution was entirely random. A much lower count than expected indicates clustering of infested (or non-infested) plants (depending on the overall density), whilst a higher count than expected indicates a uniform distribution. The extent of the clustering (size of clusters) can be determined by considering the significance of the comparisons for the first, second, third, etc neighbours. Where the proportion of plants infested is high, the test is of clustering of non-infested plants and a lack of spatial correlation or a limited number of significant neighbourhoods indicates that these non-infested plants are distributed randomly.

Approach 2 – Probability of infested plants within neighbourhood
This approach is based on calculating, for each infested plant, the probability of finding another infested plant within a defined neighbourhood. In contrast to the first approach, where neighbourhoods are defined as rings of plants around each focus plant, the neighbourhoods for this second approach contain all plants within a certain distance of one focus plant. The rationale for this approach is that if infested plants occur in clusters, then the probability of finding more infested plants within the neighbourhood of an infested plant will be higher than if infested plants are randomly distributed.

To assess the degree of clustering of each observed spatial pattern, the observed proportion of infested neighbours was compared with a distribution of similar values generated through 1000 computer simulations of patterns with the same overall infestation level. An observed value that is significantly greater than the mean obtained from the simulations indicates that the observed pattern exhibits more clustering of infested plants than would be expected if the distribution was random.

For four of the five commercial crops sampled in 1998, the proportion of cabbage aphid infested plants was too high (70% to 97% infested plants) to allow an assessment of the spatial clustering of infested plants. However, the Black-White Join-Count approach suggests that in these highly infested crops, the non-infested plants do appear to be clustered. In the fifth crop, where the overall proportion of infested plants was 20%, both approaches indicated that close neighbours of infested plants were no more likely to be infested than for a random distribution. However, slightly more distant neighbours (5 or more intermediate plants) did appear to be more likely to be infested than for a random distribution.

Considering plants infested with cabbage aphid colonies, three of the five commercial crops had infestation levels low enough to allow analysis of the spatial pattern. Similar patterns were observed to those described above, with close neighbours of infested plants no more likely to be infested than in a random distribution, and slightly more distant neighbours more likely to be infested.

Supervised control of cabbage aphid and caterpillars

The aim of this part of the project was to combine the sampling scheme, tolerance levels, plant growth stage, insecticide effectiveness and pest development into a management system for cabbage aphid and caterpillar control.

1997
In 1997, the tolerance levels used to determine whether insecticide sprays should be applied for aphid control were 20, 10 and 5% plants infested and these were used 0-10 weeks, 11-15 weeks and from 16 weeks after planting respectively. The tolerance levels used for caterpillars during the same periods were 40, 10 and 5% plants infested. A sample of 25 plants was examined on each occasion, and because the sample size was small, there were many 'no decisions'. In general, aphid control was not as good in the supervised plots as it was in those that had been sprayed routinely

or according to grower practice, although at HRI Kirton there was a reduction in the numbers of sprays applied.

1998

The aim of work done during 1998-99 was to determine the effectiveness of the management system in small plot experiments, in a single large (1 ha) plot at HRI Kirton and in plots in four commercial crops in south Lincolnshire. A further aim was to see whether aphid control could be improved by lowering the treatment thresholds and changing the accuracy of the decision-making by increasing the sample size to 40 plants/plot. At harvest, aphid damage in the supervised plots ranged from 7% to 17% damaged buttons whereas approximately 3% of buttons were damaged in the plots sprayed routinely. The 'Low' threshold treatment (threshold of 5% plants infested throughout the life of the crop) provided the most effective aphid control, which was not statistically significantly different from that in the plots sprayed routinely. Few buttons were damaged by caterpillars in the supervised plots (1-2.2%) and this was reflected in the small numbers of sprays applied to the supervised plots (means of 1.3 – 3.7) compared with those sprayed routinely (9).

The large plot (1 ha) was sampled and treated using the 'Standard' supervised treatment from the small plot experiment. At harvest, seven samples were taken from the large plot. They comprised: one from the centre of the plot, one taken close to each of the three open edges, and three taken approximately half way between the centre and each of the three open edges. Buttons from the large plot were less damaged by aphids and caterpillars than those from the plots in the small plot trial that had been treated using the same 'Standard' supervised treatment. Within the 1 ha plot there were no statistically significant differences in damage due to sample location.

The size of pest infestations in plots in commercial crops varied considerably between locations. Over all sites there was no statistically significant difference in aphid or caterpillar damage between the supervised plots and the growers' crops. Although, there were some differences between treatments at individual sites, most were not statistically significant. An average of 6.25 OP/pirimicarb sprays and 3 pyrethroid sprays were used in the supervised plots in commercial crops, compared with 5.7 OP/pirimicarb and 6.3 pyrethroid sprays in the growers' crops.

1999

Early in 1999 it became obvious that the range of insecticides available to brassica growers was likely to change considerably over the next few years as a result of the MAFF/PSD Anticholinesterase Review and the withdrawal of insecticides such as demeton-S-methyl. Alternative aphicides have been investigated in HDC Project FV 208 and of these, seed treatment with imidacloprid (1.5 mg a.i./seed) and foliar sprays of triazamate were the most effective and were likely to be taken forward for Approval (Specific Off-Label Approval or Full Approval). Thus in 1999 these treatments were included in several of the programmes that were evaluated in a small plot trial at HRI Kirton. In addition, the large plot trial done in 1998 was repeated using Approved insecticides that would be available to growers in the next 2-3 years.

Materials and methods

Small plot trial at HRI Kirton

Brussels sprouts cv Diablo were raised at HRI Kirton. Bayer supplied the seed and one batch was film-coated with imidacloprid (1.5 mg a.i./seed). The plots were planted on 20 May 1999. Each plot consisted of 18 rows x 35 plants at a spacing of 51-x 51-cm. There were five treatments and each treatment was replicated three times.

The trial was arranged as an unbalanced row and column design, each of the five treatments appearing once in each of the three rows, and in three of the five columns.

The treatments were:

A STANDARD SUPERVISED TREATMENT USING SPRAYS OF PIRIMICARB OR DIMETHOATE

A treatment threshold of 5% plants infested was used throughout for both aphids and caterpillars. The threshold was used to decide whether to spray the plot immediately, not to spray, or to return to re-assess the crop at a later date (no decision). Plots were sprayed with pirimicarb or dimethoate.

Decision ranges – numbers of plants infested to make each decision

Threshold	No spray	No decision	Spray
5%	-	0 - 1	2 – 40

N.B. Maximum probability of making an incorrect spray decision (alpha) = 0.75. Maximum probability of making an incorrect no spray decision (beta) = 0.05

B IMIDACLOPRID SEED TREATMENT FOLLOWED BY PIRIMICARB OR DIMETHOATE SPRAYS

Plants were grown from seed film-coated with imidacloprid (1.5 mg a.i./seed). A treatment threshold of 5% plants infested was used throughout for both aphids and caterpillars. The threshold was used to decide whether to spray the plot immediately, not to spray, or to return to re-assess the crop at a later date (no decision). Plots were sprayed with pirimicarb or dimethoate.

Decision ranges – numbers of plants infested to make each decision

Threshold	No spray	No decision	Spray
5%	-	0 - 1	2 – 40

N.B. Maximum probability of making an incorrect spray decision (alpha) = 0.75. Maximum probability of making an incorrect no spray decision (beta) = 0.05

C IMIDACLOPRID SEED TREATMENT FOLLOWED BY TRIAZAMATE SPRAYS – TREATMENT THRESHOLD 5%.

Plants were grown from seed film-coated with imidacloprid (1.5 mg a.i./seed). A treatment threshold of 5% plants infested was used throughout for both aphids and caterpillars. The threshold was used to decide whether to spray the plot immediately, not to spray, or to return to re-assess the crop at a later date (no decision). Plots were sprayed with triazamate.

Decision ranges – numbers of plants infested to make each decision

Threshold	No spray	No decision	Spray
5%	-	0 - 1	2 – 40

N.B. Maximum probability of making an incorrect spray decision (alpha) = 0.75. Maximum probability of making an incorrect no spray decision (beta) = 0.05

D IMIDACLOPRID SEED TREATMENT FOLLOWED BY TRIAZAMATE SPRAYS – TREATMENT THRESHOLDS 10 & 5%.

Plants were grown from seed film-coated with imidacloprid (1.5 mg a.i./seed). Thresholds for aphids and caterpillars were 10% and 5% (0-10 wk and 11wk+ from planting respectively). The thresholds were used to decide whether to spray the plot immediately, not to spray, or to return to re-assess the crop at a later date (no decision). Plots were sprayed with triazamate.

Decision ranges – numbers of plants infested to make each decision

Threshold	No spray	No decision	Spray
10%	0 – 1	2	3 – 40
5%	-	0 - 1	2 – 40

N.B. Maximum probability of making an incorrect spray decision (alpha) = 0.75. Maximum probability of making an incorrect no spray decision (beta) = 0.05

E IMIDACLOPRID SEED TREATMENT FOLLOWED BY TRIAZAMATE SPRAYS – TREATMENT THRESHOLDS 20% & 5%.

Plants were grown from seed film-coated with imidacloprid (1.5 mg a.i./seed). Thresholds for aphids and caterpillars were 20% and 5% (0-10 wk and 11wk+ from planting respectively). The thresholds were used to decide whether to spray the plot immediately, not to spray, or to return to re-assess the crop at a later date (no decision). Plots were sprayed with triazamate.

Decision ranges – numbers of plants infested to make each decision

Threshold	No spray	No decision	Spray
20%	0 – 4	5	6 – 40
5%	-	0 - 1	2 – 40

N.B. *Maximum probability of making an incorrect spray decision (alpha) = 0.75.*
Maximum probability of making an incorrect no spray decision (beta) = 0.05.

For all thresholds, the maximum probabilities of making incorrect decisions are at the threshold minus 20% of the threshold (incorrect spray decision) and plus 20% of the threshold (incorrect no spray decision).

UNTREATED AREA

A single untreated plot (8 rows x 25 plants) was located between the small plot experiment and the large plot.

Sampling intervals
Aphid and caterpillar numbers were monitored in five untreated areas of Brussels sprouts in South Lincolnshire as part of the HRI Kirton Pest Monitoring Service. This information was used to adjust the interval between sampling visits to the supervised plots.

Following a '*No spray decision*' the sampling interval was 2 weeks (1 week if cabbage aphid colony and/or diamond-back moth + small white butterfly caterpillar numbers had doubled since the monitoring plots were last sampled).

Following a '*No decision*' the sampling interval was 1 week (3 days if cabbage aphid/caterpillar numbers had doubled in the monitoring plots).

Following a '*Spray*' decision the sampling interval was 2 weeks.

Sampling strategy
On each sampling occasion a random sample of 40 plants was inspected from a central assessment area of 8 rows x 15 plants (leaving a 5-plant guard around the perimeter). Only the presence of wingless cabbage aphids and caterpillars was used to make spray decisions. The percentage of plants infested with peach-potato aphids and with moth and butterfly eggs and pupae was recorded also but this information was not used to make treatment decisions.

Insecticides
The insecticides specified above were applied to control aphids. Deltamethrin was used to control caterpillars.

Records taken
On each sampling occasion, records were taken of the numbers of plants (out of a total of 40) infested with each species of aphid (cabbage aphid, peach-potato aphid) and caterpillar (diamond-back moth, cabbage moth, small white butterfly, large white butterfly, garden pebble moth, silver Y moth).

Harvest assessments
A random sample of 30 plants was taken from each plot in mid-November. Because the harvest assessments took several days, one replicate was harvested at a time. The stems were split into thirds (top, middle and bottom) and the buttons from each region of the stem were assessed individually for aphid, caterpillar, slug and non-pest damage. The weights and numbers of buttons in each category were recorded. Additional samples of 15 plants were taken systematically from the guard rows of each plot and assessed as described above.

Large plot at HRI Kirton
Brussels sprouts c.v. Diablo were raised by a commercial propagator and machine planted on 18 - 21 May 1999.

Treatment
The large plot was sampled and treated using the standard supervised treatment (Treatment A) from the small plot experiment.

Sampling strategy
On each occasion, 40 plants were sampled at random from each of the three open edges of the plot. One of these was adjacent to the road (which had a grass verge), one was adjacent to a small copse and the third to an area of grass (Figure 1). Samples were taken from rows 6-10. A 40-plant sub-sample was selected at random from these 120-plant samples (approximately equal numbers from each of three areas) and used to make the treatment decisions.

Insecticides
Sprays of pirimicarb or dimethoate were applied to control aphids. Deltamethrin was used for caterpillar control.

Records taken
On each sampling occasion, records were taken of the numbers of plants (out of a total of 40) infested with each species of aphid (cabbage aphid, peach-potato aphid) and caterpillar (diamond-back moth, cabbage moth, small white butterfly, large white butterfly, garden pebble moth, silver Y moth).

Harvest assessments
At harvest, ten 30-plant samples were taken from the large plot. They comprised samples taken close to each of the four edges (grass, road, copse, cereal) with further samples taken at two distances (intermediate between edge and middle of crop, middle of crop) further into the crop from three of edges (grass, road, copse) (Figure 1). The stems were split into thirds (top, middle and bottom) and the buttons from each region of the stem were assessed individually for aphid, caterpillar, slug and non-pest damage. The weights and numbers of buttons in each category were recorded. The three parts of the stem were treated as sub-plots for the purpose of statistical analysis.

Results

Assessments through the life of the crop

Cabbage aphid numbers on the five monitoring plots started to increase from early July (> 1 colony/plant by 8 July) (Figure 2). Aphid numbers then increased continuously until early September, after which they began to decline.

Diamond-back moth and small white butterfly were the major caterpillar pests. However, numbers of both species were very low. Diamond-back moth caterpillars were most numerous from mid July until mid September (Figure 3). Small white butterfly caterpillars were found from late July until October (Figure 4).

Small plot trial at HRI Kirton

Figures 5a-e and 6a-e show the numbers of plants infested with aphids and caterpillars respectively in each of the supervised plots in the small plot trial at HRI Kirton. The numbers of infested plants used to trigger insecticide sprays on each plot and the dates on which spray decisions were made are shown on each graph. The numbers of plants infested with aphids depended on the treatment regime applied. Plants in treatment A became heavily infested with aphids early in the season, in July, and infestation levels remained high until harvest. This was the only treatment where the plants were grown from insecticide-free seed.

Caterpillar numbers were very low throughout the trial. Most sprays were triggered in July – August.

Large plot at HRI Kirton

Figures 7-8 show the numbers of plants infested with aphids and caterpillars along each of the three edges of the large plot on each sampling occasion.

The numbers of plants infested with aphids increased during late June – early July and remained high from then onwards. Infestation levels were similar on all three edges. Few plants were infested with caterpillars and the numbers of infested plants just exceeded the treatment threshold on four occasions from late June until late September.

Numbers of sprays applied

Small plot trial at HRI Kirton

The numbers of visits to make decisions and the numbers of 'No decisions' and sprays applied are shown in Table 1. Over all supervised plots in the small plot trial there was a mean of 12.3 sampling visits per plot to make decisions about aphid control and 10.8 visits to make decisions about caterpillars. Because aphid numbers were relatively high, 57% of the visits for aphids resulted in 'spray' decisions, 8% resulted in 'no spray' decisions and 35% of visits resulted in 'no decision'. Caterpillar numbers were considerably lower, so only 14% of visits resulted in a 'spray' decision, 27% in a 'no spray' decision and a larger proportion, 59%, in 'no decision'.

The mean numbers of sprays applied to control aphids in the supervised plots in the small plot trial ranged from 5.3 (Treatment E) to 9 (Treatment B) (Table 1). The numbers of sprays applied for caterpillar control varied between one and two.

Large plot at HRI Kirton
In the large plot, there were 9 sampling visits to make decisions about aphid control and 11 visits to make decisions about caterpillars. Because aphid numbers were high, 100% of the visits for aphids resulted in 'spray' decisions. Only 36% of visits resulted in a 'spray' decision for caterpillars, 9% in a 'no spray' decision and a larger proportion, 55%, in 'no decision'.

A total of 9 dimethoate/pirimicarb sprays for aphid control and 4 deltamethrin sprays for caterpillar control were applied to the large plot at HRI Kirton (Table 1).

Harvest assessments

Small plot trial at HRI Kirton

The results of statistical analysis of the trial are shown in Tables 2a-c. The harvest data were analysed using the Restricted Maximum Likelihood (REML) approach to allow adjustment for spatial variability. The effects of treatment, stem part (HEIGHT) and the interaction between these two factors were assessed using Wald statistics. The calculated values were compared with tabulated values of the appropriate chi-squared distribution, and effects significant at the nominal 0.05, 0.01 and 0.001 levels are shown. 'NS' indicates lack of significance at the 0.05 level.

A range of Standard Errors of the Difference (SEDs) were calculated within the REML analysis, the appropriate value for each comparison depending on the number of within row concurrences (with additional variation due to a missing data value in the analyses of weights). The value shown is the maximum value for any pair of means.

All values are based on 30 plants per plot, expressed per part stem (approximately one-third of a stem). To calculate totals for 30 stems for a given treatment, the values can be multiplied by three.

Pest management strategy had no effect on the total number or weight of buttons recovered at harvest (Table 2a). Yield was affected by position on the plant (top, middle or bottom of the stem) [$p<0.001$].

Similarly, pest management strategy had no effect on the percentage of buttons damaged by number or by weight (Tables 2b-c). In all, aphids damaged 6-16% buttons (by weight or by number), and caterpillars approximately 1%.

Over all treatments, buttons at the top of the stem were least damaged by aphids and caterpillars and buttons at the bottom, the most damaged (percentage of buttons by weight [$p<0.001$ (aphids), $p<0.01$ (caterpillars)]; percentage of buttons by number [$p<0.001$]) (Tables 2b-c).

Large plot at HRI Kirton

Comparisons were made between the large plot, the small plots (Treatment A) and the untreated plot at HRI Kirton. The results of the statistical analysis are shown in Tables 3a-d. A set of nested factors was used to partition the variation, so that specific comparisons could be made:

Control	Comparison of untreated with supervised
Size	Comparison of small plots with samples from the large plot
Edge 1	Comparison of cereal edge with the other edges
Edge 2	Comparison of grass, road and copse edges
Distance	Comparison of different distances from edge (edge vs intermediate vs middle)

The interaction between the last two factors was not included, to ensure sufficient precision for the estimate of the underlying variability (residual mean square).

In addition samples were divided into top, middle and bottom parts of the stem, and differences between these stem parts were assessed, together with the interactions between the above treatment effects and stem part.

Table 3a shows the probabilities associated with the F-tests for the various treatment effects on the percentage damaged buttons by weight and number, and these are given at the nominal significance levels of 0.05, 0.01 and 0.001.

All values are based on 30 plants per plot, expressed per part stem (approximately one-third of a stem). To calculate totals for 30 stems for a given treatment, the values can be multiplied by three.

Plant location within the 1 ha plot had no effect on the total weight or number of buttons recovered at harvest. Similar yields were obtained from the 1 ha plot, the small plots and the untreated plot ($p>0.05$).

As would be expected, buttons in the untreated plot were more damaged by aphids than those in the supervised plots ($p<0.001$ in comparisons by percentage weight and number)(Tables 3c-d). For example, 77% buttons (by number) were damaged by aphids in the untreated area, 15% in the small plots (all treatments) and 8% in the large plot. For caterpillars, 0.7% buttons were damaged in the untreated plot, 1% in the small plots and 1.8% in the large plot (Tables 3c-d). Because the numbers of buttons damaged by caterpillars were so small, there was no statistically significant difference between the untreated and supervised plots.

As in 1998, a larger percentage of buttons from the small plots were damaged by aphids than those from the 1 ha plot ($p<0.05$). However, again as in 1998, there were no statistically significant differences in the percentage of buttons damaged by aphids at the different locations in the 1 ha plot.

Over all treatments, buttons at the top of the stem were least damaged by aphids and caterpillars and buttons at the bottom, the most damaged ($p<0.001$ for all parameters analysed) (Tables 3c-d).

DISCUSSION

Development of a practical supervised pest control protocol

The increased pressure on growers to adopt systems of supervised pest control, and the need to collect data to justify decisions to treat crops, raises questions about how best to collect such data to allow reliable decisions to be made. Work within this project (and related projects) has provided answers to some of these questions, and for seven identified areas of choice, the options identified during this project, together with recommended choices are discussed below.

The seven areas are:

1. Where to sample?
2. When to sample?
3. What to sample?
4. How many plants to sample?
5. How to summarise the collected data to make decisions?
6. What treatment thresholds to use?
7. What risks of making incorrect decisions to allow?

It is important to realise that many of the options and choices within these areas are inter-related. Some of these inter-relationships are highlighted below.

Where to sample?

This area covers both the choice of sampling locations within a field, and the sampling intensity (spacing between sampled plants) within the location.

Intensive sampling of crops has shown that the distribution of insect pests within a crop is unlikely to be uniform and that pests may be aggregated in particular areas. Work done in commercial brassica crops over the last few years (FV 194) has shown that, on average, both the numbers of cabbage aphids and the proportion of plants infested with cabbage aphids tend to be higher at the edges of the crop, and the same is true for caterpillars (FV 163). In addition there can be considerable variation in infestation levels both within and between the individual edges of a crop, although the different infestation levels do not appear to be associated with particular features of the field edges (e.g. orientation, hedge composition or height).

Recommendations: *By just sampling plants from close to the edges of fields, growers will obtain an estimate of the worst scenario for pest infestation levels within the field. However, a representative sample can be obtained only by sampling plants from all edges, and from a considerable length of each edge. The recommended approach is therefore to sample plants from a number of locations close to the field edges. How the information gathered from these samples is then used to make treatment decisions depends both on the sample size and the summary method. Where sufficiently large samples are assessed along each edge, a separate decision can be made for each edge, and the overall decision based on the worst infested edge. Where a grower decides to treat parts of the field differently (e.g. centre and areas near to each edge), a representative sample needs to collected from each of these areas. If a sufficient size of sample is only obtained by combining the samples from all edges, then the* *treatment decision is made based on the combined sample. This is straightforward when a fixed-size sample approach is used, but an, as yet, unsolved problem when using a sequential sampling approach.*

Most decision-making schemes include an assumption that the observations made on sampling units are independent of each other. Ideally this means that plants need to be sampled completely at random from within an area. However, this is unlikely to be practical. An alternative is to select sampled plants systematically, ensuring that, if there is any spatial correlation of the infestation status of neighbouring plants, the distance between sampled plants is sufficiently large to minimise such correlations.

The results of the analysis of the spatial distribution of aphid infested plants suggest a different spatial pattern to that observed previously for caterpillar species. For many of the caterpillar data sets, two analysis approaches indicated strong clustering of infested plants, often extending to eight intermediate plants, with first neighbours almost always being more likely to be infested than for a random distribution. This type of spatial pattern agrees with knowledge of caterpillar biology, with eggs being laid either in clumps on a single plant (cabbage moth, large white butterfly, garden pebble moth), or, apparently, individually on a group of adjacent plants (diamond-back moth, small white butterfly).

In contrast, aphid infestations do not appear to be clustered in the same way, with adjacent plants no more likely to be infested than for a random distribution. The higher incidence of more distant infested neighbours together with a visual inspection of the patterns suggests a more random distribution of aphid infested plants, although with some locally more dense patches. This more random distribution agrees with the results obtained by Joe Perry (IACR-Rothamsted) from data collected within the MAFF-funded project led by Bill Parker (HH1023TFV). The patches of locally more dense infestations are probably related to some crop feature that makes the patch more attractive to aphid infestation. Unfortunately neither the data analysed by Joe Perry, nor that collected in this project, covers a sufficiently large enough area of crop to confirm this infestation pattern. Again, the lack of any strong clustering of aphid infested plants agrees with pest biology, with individual aphids each being responsible for single infestation events, and little movement of wingless aphids between adjacent plants.

Recommendations: *In devising a joint strategy for sampling crops for caterpillar and aphid infestations, the lack of any strong spatial pattern for aphid infestations suggests that a scheme based on the spatial distribution of caterpillars should be used. The current recommendation is for sampled plants to be no closer than 10 plants apart to avoid over-sampling the same caterpillar infestation focus. Such a sampling scheme should also provide a representative sample from the random distribution of plants infested with aphids.*

When to sample?

This area is concerned with both when to start sampling a crop, and how frequently to re-sample a crop after particular decisions.

Observations during this project indicated that the dates when aphids first infested crops varied considerably between years, and there is also evidence of variation between locations. Similar variation in the timing of infestations has been observed for the range of caterpillar species. For some species, forecast models have been, or are being developed, to provide predictions of the start of pest activity based on local meteorological data. Further development of these models may allow prediction of other features of the pest life cycle, such as the timing of the aphid 'crash'. Within this project, the start of pest activity has been identified by monitoring plots of untreated plants. Unfortunately neither forecast models nor monitoring plots provide reliable data on the size of infestations, so that crop sampling is still necessary.

Recommendations: *Where forecast models are available these should be used to predict the start of pest activity, and hence the start of crop sampling. Where forecast models are not available, sets of monitoring plants could be used to identify the start of pest activity (and hence the start of crop sampling). Alternatively, sampling could commence immediately after planting.*

The frequency of crop sampling should be dependent on a number of factors, including the efficacy and persistence of insecticide treatments and the estimated rate of development of pest infestations. The schemes used within this project have generally used a two-week interval following either a 'spray' or 'no spray' decision, with a shorter re-sampling interval of one-week following a 'no decision'. In another project, the re-sampling interval was halved when the mean daily temperature exceeded a specified level. Ideally, the re-sampling interval should be expressed on a thermal-time scale, the interval depending on the thermal-time required for some specified change in pest numbers or in the life cycle of the pest, and to the efficacy of the insecticide treatments. Identification of such intervals, however, requires further development of pest life-cycle and insecticide efficacy models.

A number of modifications to the basic sequential sampling approach have been suggested in the literature, which determine the size of the re-sampling interval from the difference between the observed infestation level and the threshold. As observed levels get further below the threshold, a longer re-sampling interval is used, whilst as observed levels further exceed the threshold, the re-sampling interval is progressively shortened until the minimum re-sampling interval is reached.

It may also be appropriate for the re-sampling interval to depend on the threshold being used. Where a higher threshold is acceptable, an insecticide treatment may reduce the infestation to a level substantially lower than the threshold, so that the infestation will take longer to recover towards the threshold level.

Recommendations: *A minimum re-sampling interval following insecticide applications should be based on the efficacy and persistence of the insecticide used. This may vary depending on weather conditions. The re-sampling interval also depends on the rate of pest development and should be shorter when temperatures are high or when there is an increased risk of new infestation. Assuming that a simple* *'spray – no decision – no spray' decision making system is used, the same re-sampling intervals are recommended when the 'no spray' decision is reached, and re-sampling intervals half the length when a 'no decision' is reached.*

What to sample?

This area is concerned both with the selection of the sampling unit, and with what is recorded from each sampling unit.

Within this project all the sampling schemes have considered a single plant as the sampling unit. Groups of adjacent plants could be considered as the sampling unit, counting the numbers of pests over the whole group or recording the presence or absence of pests across the whole group. However, this provides little additional information with a significant additional cost – the same number of sampling units would need to be assessed as for single plant sampling units to reach a decision, with more plants assessed per sampling unit.

Recommendations: *Individual plants should be considered as the sampling unit, selected from within the sampling area in a fairly systematic manner, according to the inter-plant spacing based on the spatial pattern of caterpillar infested plants, as specified above.*

The choice of what to record from each sampling unit (plant) is basically between a full count of the number of each pest species present, and a simple record of the presence or absence of each pest species. The former requires treatment thresholds to be expressed in terms of the mean number of pests per plant at which treatment is considered necessary, together with reliable information about the statistical distribution of the number of pests per plant. The latter requires treatment thresholds to be expressed in terms of the proportion of infested plants above which treatment is considered necessary. In this and related projects, data has been collected to allow estimation of the statistical distribution of the number of pests per plant, and also of the relationship between the mean number of pests per plant and the proportion of infested plants. This relationship appears to be fairly consistent, particularly for caterpillars, although results from Joe Perry's work (MAFF project HH1023TFV) suggest that the relationship for aphids may alter during the course of the growing season. The existence of such a relationship, together with the obvious reduced cost of assessing plants merely for the presence or absence of pest species, has led to the use of presence/absence sampling in all experimental work testing supervised control schemes within this project. The use of presence/absence data also leads to simpler decision-making processes.

A possible modification of the presence/absence approach is the use of a tally count. Instead of the presence of a single pest of each species resulting in the recording of the plant as being infested, in this approach the presence of more than some pre-specified tally is required before the plant is recorded as being infested. For aphids, one possible adaptation of this approach would be to only record a plant as being infested if an aphid colony is present. Another option for aphids is whether the assessment should be based on the presence of wingless aphids only, of both winged and wingless aphids.

Recommendations: *Record simply the presence or absence of each pest species on each sampled plant. Future work may lead to a system based on complete counts (or scores) for aphids, to take account of the different 'proportion-mean number' relationships suggested.*

How many plants to sample?

The decision about the number of plants to sample is strongly related to the method used to summarise the collected data to make decisions, the treatment thresholds used, and the acceptable risks of making incorrect decisions.

As shown by the MATLAB simulation results reported earlier, the reliability of the estimated infestation level increases (% cv decreases) as the sample size increases, and consequently so does the reliability of the decision reached. However, an increased sample size also increases the cost of collecting the data. The relationship between sample size and treatment threshold is also fairly simple, with increased sample sizes required to reliably detect deviations from lower thresholds. The relationships between sample size and the risks of making incorrect decisions are more complicated, but, in general, an increased sample size will allow these risks to be ascribed more accurately. Finally, the choice of decision-making process can have a great effect on the average sample size assessed. As noted below, sequential sampling systems generally require a larger maximum sample size to provide the same operating characteristics to similar fixed-size sampling systems. But, except when the true infestation level is close to the threshold, using a sequential sampling system will on average require a smaller sized sample to be assessed before a decision is reached, than is required for the equivalent fixed-size sampling system.

A further consideration of sample size is concerned with how different areas of the field are to be treated, as discussed above. If separate decisions are to be made for each of a number of crop areas, then a sufficient sample size needs to be taken from each of these areas. Given the potential variability in infestation levels between the edges of a field, this is also the ideal situation when sampling several areas, basing the decision on the most infested area. However, if this approach leads to samples that are too large to be either practical or economic to assess, then the combined sample across the different crop areas should be of a sufficient size to provide a reliable estimate of the infestation level, and hence give a reliable treatment decision.

The importance of the choice of sample size can be demonstrated by calculating, for a range of sample sizes, the maximum percentage infestation level for which the probability of observing a given number of infested plants is greater than 5%. This is the upper 95% confidence or detection limit for the actual percentage infestation given an observed number of infested plants for each sample size.

Sample size	Number of infested plants				
	0	1	2	3	4
30	9.5	14.2	18.4	22.3	26.0
50	5.8	8.7	11.3	13.7	16.0
75	3.9	5.9	7.6	9.2	10.8
100	3.0	4.4	5.7	7.0	8.1
125	2.4	3.6	4.6	5.6	6.5
150	2.0	3.0	3.8	4.7	5.5
175	1.7	2.5	3.3	4.0	4.7
200	1.5	2.2	2.9	3.5	4.1

For the supervised control experiments in this project, samples of either 25 plants (1997) or 40 plants (1998-9) were used to make decisions. For the fixed-size sampling schemes used, however, these sample sizes did not allow a 'no spray' decision to be reached at the 5% threshold (all years) or the 10% threshold (1997 only).

Recommendations: *The choice of sample size is influenced greatly by a number of other decisions discussed in this section. In general, the larger the sample-size the more confidence the grower can have in the decision reached. However, where relatively high treatment thresholds are being used a smaller sample size can be used with little loss of precision or confidence. If a sequential sampling system is employed, then the maximum sample size can be chosen to be larger than that for an equivalent fixed-size sampling system, as, on average, the size of the assessed sample will be considerably below the maximum.*

The final decision on sample-size must be taken alongside decisions on thresholds, the risk of making an incorrect decision, the decision-making scheme used, and how the crop is to be treated. The sample size can be selected by comparing the operating characteristics and other properties (see below) of the sampling scheme with desired features. The choice of sample size remains a compromise between the costs of obtaining additional information (increasing the sample size), and the risks associated with reaching incorrect decisions or being unable to reach a 'positive' decision.

The decision making process

This area is primarily concerned with how to use the information collected by sampling a crop to reach a decision about treatment, but within this are decisions about re-sampling intervals, sample size, thresholds and the risks of reaching incorrect decisions.

There are two basic approaches that are used to make decisions based on the observations collected from a sample of plants. Both approaches generally lead to three possible outcomes. Two of the outcomes are obvious – a decision to treat, because the treatment threshold has been exceeded, and a decision not to treat, because the treatment threshold has not been exceeded. In addition an intermediate outcome is often included – a decision to collect more information (a 'no decision'), because the observed infestation level is too close to the treatment threshold to be certain. In this project only schemes based on presence/absence data have been considered, although similar schemes have been developed elsewhere based on counts of pests on each sampled plant.

The simpler approach (as used in experimental plots within this project) requires a specified number of plants to be sampled to make each decision (although the number will probably vary with treatment threshold), and is generally referred to as a fixed-size sampling scheme. For a given sample size it is possible to calculate, based on the values of certain other parameters, the ranges of numbers of infested plants which should lead to each of the possible decisions, and the observed number of infested plants is simply compared with these ranges. The parameters that can affect these ranges are the maximum risks of reaching a 'treatment' decision at a particular infestation level below the threshold and of reaching a 'no-treatment' decision at a particular level above the threshold. In the schemes used within this project, these maximum risks have usually been calculated at the threshold plus or minus 20% of the threshold (plus or minus 10% at the 40% threshold).

Where the actual infestation level is considerably above (or below) the threshold, it may be possible to observe sufficient infested (or not-infested) plants to reach a treatment (or 'no treatment') decision without having to assess the complete fixed-size sample. This idea leads to the alternative approach of sequential sampling. In this approach, after each plant has been sampled and assessed, a decision is made as to whether sufficient information has been collected to be confident that either a 'treatment' or 'no treatment' decision can be made, or that further information needs to be collected. As with the fixed-size sampling approach described above, the properties of a sequential sampling scheme are related to the nominal risks of reaching a 'treatment' decision at a particular infestation level below the threshold and of reaching a 'no-treatment' decision at a particular level above the threshold. In theory sequential sampling schemes have an unlimited maximum sample size, but it is usual in practice to specify a maximum sample size, which, if reached, indicates that the intermediate outcome ('no decision') should be taken. With many sequential sampling schemes a minimum sample size is also specified, below which a decision cannot be reached. Sequential sampling schemes are usually presented in graphical form, relating the number of infested plants to the number of plants assessed, and indicating the regions of this data-space within which each of the decisions should be taken.

Several modifications of the sequential sampling approach have been proposed elsewhere. These include the batch sequential approach, in which a decision is made after each group of plants have been assessed rather than after each individual plant, and adaptive frequency methods, where the re-sampling interval depends on how far the estimated infestation level is from the threshold (observed levels below the threshold lead to longer re-sampling intervals, those above the threshold to shorter re-sampling intervals).

The performance of each of these decision-making approaches can be assessed by considering the operating characteristics and expected (average) sample size across a range of infestation levels. As noted above, sequential schemes will generally require a smaller sample size than the equivalent fixed-size scheme when the infestation level is very different from the threshold, but will often need larger sample sizes close to the threshold. The operating characteristic of a scheme is, formally, the probability of reaching a treatment decision across the range of infestation levels, but similar probabilities can be calculated for the other possible outcomes. These performance summary statistics can be compared with desired properties to choose a suitable sampling scheme (decision making process, sample size, risks of reaching incorrect decisions) for any situation.

Recommendations: *Ideally a sequential sampling approach should be adopted, selecting an appropriate chart based on the grower's required properties. Some further work is required, however, to develop a system to provide the rapid generation of appropriate decision-making charts for a range of parameter values. One constraint on using this approach at present, however, is that each area of a field would need to be sampled separately, with a final treatment decision based on the "worst" edge scenario. Some training of assessors would also be required to allow the practical implementation of such schemes.*

Fixed-size sampling schemes may provide a simpler alternative, although with the disadvantage of requiring larger samples to be assessed when the infestation level is substantially different from the threshold. Similarly, some further work is required to develop a system to provide the rapid generation of schemes for a range of parameter values.

Treatment thresholds

The treatment thresholds used within this project were based on those used in previous MAFF-funded projects, which were based on recommendations given in published Dutch research for various cabbage crops. As already mentioned, the choice of treatment thresholds both influences and is influenced by a number of other decisions, but ultimately this decision must be based on the relationship between observed levels of damage and the level of infestation allowed at various stages during crop growth. This information is, as yet, not available.

Whilst the grower's priority continues to be the production of pest-free/blemish-free produce, it would seem that the use of low thresholds is essential. However, the implication of using low thresholds is that to provide reliable decisions requires larger sample sizes. Within this project (and related projects) it has been shown that for caterpillars, higher thresholds (40% compared with 5%) can be used during the early stages of crop development without detrimentally affecting the harvested crop yield and quality. Similarly for aphids, using slightly higher treatment thresholds (20% compared with 5%) during the early stages of crop development, in combination with a seed treatment, appeared to have no detrimental affect on yield and quality in the 1999 trial.

Recommendations: *In the absence of any better information, the treatment thresholds used in the small plot trials during this project should be used. For aphids, where seed treatment is available, higher treatment thresholds (20% or 10%) can be used during the first ten weeks after planting. Where a 5% treatment threshold is used, however, a sample size larger than that used in this project is recommended, to allow a 'no treatment' decision to be reached if appropriate.*

Risks of incorrect decisions

As noted above, choices in this area are closely influenced by, and related to, many of the other decisions. As with the decisions about sample size and treatment threshold, these choices are highly individual, depending on how cautious a grower wishes to be.

In the later years of this project, the risk of treating when the true infestation level is below the threshold has been set quite high. The effect of this is to reduce the minimum number of infested plants required to trigger a treatment decision, thus causing insecticides to be applied when the true infestation level could be substantially below the threshold. This risk can be thought of as the "consumer's risk" – the risk associated with having unnecessary insecticides applied.

Throughout this project the risk of not treating when the true infestation is above the threshold has been kept low, at a probability of 0.05. This has the effect of keeping the maximum number of infested plants at which a 'no treatment' decision is triggered quite small, and, for particularly low treatment thresholds, eliminating the possibility of this outcome being reached. This can be thought of as the "grower's risk" – the risk associated with not controlling pests when required.

The combination of these two risks affects the width of the 'no decision' interval, and therefore the total amount of sampling that is required. The wider the 'no decision' interval, the more likely that a grower will be unable to reach a 'firm' decision, and will therefore need to re-sample to gather additional information.

It should be noted that associated with the decision on the (nominal) maximum size of each of the risks is the infestation level at which that maximum risk occurs. Within this project, the decision-making schemes used have defined these maximum risks to be at plus or minus 20% of the treatment threshold (plus or minus 10% at the 40% threshold). In practice a grower may want to select a sampling scheme that gives one level of risk at one infestation level below the treatment threshold, and a second level of risk at another infestation level below the treatment threshold. This can probably be achieved by careful consideration of the operating characteristic (and similar statistical summaries) of a range of sampling schemes.

Recommendations: *These properties of sampling schemes should be selected in conjunction with decisions about sample size and the decision-making process, but growers will probably wish to keep the "grower's risk" relatively low, whilst allowing the "consumer's risk" to be a bit higher. The values selected should be dependent on the associated "costs" of incorrect decisions.*

In addition to these two risks of reaching incorrect decisions, there is a third risk associated with any decision-making scheme. This is the risk of collecting insufficient information to be certain that either a spray or a no-spray decision is appropriate. The size of this risk is almost entirely a function of sample size, the larger the sample, the smaller the risk. In selecting an appropriate decision-making scheme for any situation, the maximum size of this risk, usually occurring for infestation levels close to the threshold, should be considered.

Supervised control of cabbage aphid and caterpillars

The aim of this project is to develop a supervised system of aphid control so that insecticide sprays are applied only when necessary and insecticide use is minimised. To ensure this, decision-making must be based on the timing of pest immigration and the subsequent development of infestations.

Timing of pest immigration
The timing of aphid immigration varies considerably from year to year, so that the date on which the first treatment is necessary will vary also. In an HDC-funded study (FV 121), using data collected over a number of years, the date by which > 1 aphid/plant was observed in untreated monitoring plots at HRI Kirton, HRI Wellesbourne and ADAS Arthur Rickwood varied from 17 May to 5 August.

In 1997, in supervised plots at HRI Kirton and in a commercial crop at Frampton, Lincolnshire, the first sprays were applied on 20 August and 28 July respectively, 14 and 11 weeks after planting. In contrast, in 1998, the first aphicide spray was applied on 12 June at HRI Kirton (approximately 4 weeks after planting). As a consequence of the earlier aphid infestation, an average of 6.7 aphicide sprays was applied to the 'High threshold' supervised treatment, compared with 2.3 – 3.3 aphicide sprays applied to plots treated using the same thresholds in 1997. Similar levels of aphid control were achieved.

In 1999, the first decision to spray was made in early June. Plots grown from insecticide-free seed received 8-9 aphicide sprays, using a treatment threshold of 5% throughout. Aphid numbers increased continuously until early September, after which they began to decline.

The diamond-back moth is the major caterpillar pest of brassicas in Lincolnshire and because it is a migrant species, the timing of immigration into susceptible crops varies considerably from year to year. Forecasts to predict the timing of infestation by the diamond-back moth and other caterpillar species have been developed in LINK project FV 163 and are being refined and validated in HDC project FV 163a.

Pest control during 1999
At harvest, less than 1% of buttons in the untreated plots was damaged by caterpillars and there were no statistically significant differences between treatments or between supervised plots and the untreated control. This justified the application of few deltamethrin sprays.

In contrast, aphids damaged 77% buttons in the untreated plot and this level of infestation was reduced to 6-16% in the small plot trial (representing 79-92% control) and 8% in the large plot trial. There were no statistically significant differences between the treatments used in the small plot trial. However, the plots least infested at harvest (Treatment E) received fewest sprays (mean of 5.3 vs mean of 9 sprays applied to the large plot and to Treatment B). Although application of triazamate (Treatments C-E) reduced the numbers of sprays applied to achieve similar levels of aphid control compared with the 'commercial standard' (5-7 sprays vs 8-9), seed treatment with imidacloprid did not. This is the only trial out of six (remainder done in Projects FV 208 & FV 208a), where the use of brassica seed film-coated with imidacloprid has not reduced the numbers of aphicide sprays required subsequently in a supervised system. However, although spray numbers were not reduced, routine sampling throughout the season (Figures 5a-e) showed that seed treatment with imidacloprid did suppress aphid infestations early in the season. The same figures also show that sprays of triazamate suppressed aphid infestations more effectively than the 'commercial standard'.

Summary of trials during 1997-99
The data from the 14 of the experimental treatments applied to Brussels sprouts plots in Lincolnshire in 1997-1999 (12 treatments at HRI Kirton, 2 treatments in a commercial crop) are summarised in Figure 9. All treatments used insecticides Approved for aphid control at the time (demeton-s-methyl, pirimicarb, dimethoate, heptenophos, nicotine). Caterpillars were controlled with *Bt* or deltamethrin. All insecticides were applied at recommended rates. A variety of treatment thresholds were used in these experiments, which were exposed to different levels of pest pressure. As a result, the numbers of sprays applied varied considerably.

The effectiveness of each spray programme for aphid control was measured in terms of the percentage of buttons infested with aphids at harvest. During these experiments, levels of aphid infestation at harvest in the insecticide-free control plots ranged from 13 to 77% buttons infested.

Figure 9 shows the relationship between the effectiveness of each spray programme (compared with the appropriate untreated control plots) and the numbers of OP/carbamate/pyrethroid sprays applied. The pyrethroid sprays are included, because although they were not targeted at aphids, they do provide some aphid control. It was assumed that *Bt* would have no impact on cabbage aphid survival.

There is a clear relationship between the numbers of sprays applied and the effectiveness of the spray programme when compared with the untreated control plots. There is some scatter around the fitted curve, but this would be expected, since several insecticides were used, and these were applied at different times during the summer (insecticides tend to be more effective in July-August than later on). Extrapolation from the fitted equation indicates that using this range of insecticides, approximately 18 sprays would have to be applied to a crop to achieve 90% control. Thus on a crop where 50% buttons would be infested in the absence of insecticide treatment, 18 sprays would be expected to leave 5% of buttons infested at harvest. Obviously, in years when infestations are low, acceptable levels of control could be achieved with fewer sprays. However, in years of heavy infestation it would not be possible to achieve acceptable levels of control without the application of large numbers of sprays. At HRI Kirton, infestation levels in untreated plots were 34% (1997), 58% (1998) and 77% (1999). Thus if 95% control was the target, then the estimated numbers of sprays (including pyrethroids) required to achieve this level of control would have been 12, 19 and 24 respectively.

The relationship between the numbers of sprays and percent aphid control shows the value of a supervised system. If sprays were applied routinely, then in years of light infestation, some sprays would be applied unnecessarily. Alternatively, more sprays than would be applied routinely might be required in years of heavy infestation. One of the factors that appear to reduce the size of the infestation and consequently the numbers of sprays applied, is late immigration. Earlier MAFF-funded studies at HRI Kirton and HRI Stockbridge House during 1994 and 1995 showed that sprays applied before aphids had established in the crop had no effect on infestation levels at harvest. The timing of immigration can be forecast from temperature data, although such forecasts have not been validated extensively. In addition, careful crop monitoring on a local or regional basis should identify when aphids arrive.

Supervised systems are also valuable for caterpillar control. Infestations have been light over the last two years and very few sprays have been applied to the supervised plots, with no marked loss of control (Table 5). Routine programmes have included 9-11 sprays for caterpillar control. In contrast, infestations were particularly high in 1996, with a consequent increase in the number of insecticides applied to control caterpillars in supervised plots (average of 10.7 at HRI Kirton; LINK Project FV 163).

The severity of pest infestation differed between crops (commercial crop plots in 1997 and 1998) and studies on the distribution of aphids and caterpillars have shown that different areas of the crop may suffer different levels of infestation. Pests are likely to be more numerous on the edges of the crop and infestation levels may differ both between and along different edges. In the large plot, information collected from the three 'true' edges of the crop was combined to make spray decisions. However, at harvest there were no statistically significant effects of location within the crop on pest damage in either 1998 or 1999.

Although there is a 'nil tolerance' for pest damage on harvested Brussels sprouts, in reality it is very difficult to achieve 100% control of aphids on commercial crops even with the application of large numbers of sprays. This is partly due to the inaccessibility of aphids to insecticides and also to the relative ineffectiveness of the insecticides Approved currently. In the small plot trials at HRI Kirton, the levels of aphid infestation achieved with the best supervised programme were generally about 7%. However, this is the result of assessing all the buttons on the stem (including those at the base of the stem) and of very careful examination of each button (under the wing leaves).

Decision-making

The outcome of the trials done in 1997-99 is summarised in Tables 4 & 5. In 1997, a sample of 25 plants was examined on each occasion to make treatment decisions. Because the sample size was small, there were many 'no decisions' for both aphids and caterpillars.

In 1998 and 1999, the sample size was increased to 40 plants per plot, with the aim of increasing the precision of decision-making and facilitating a greater number of positive decisions ('spray' or 'no spray'). In the small plot trial in 1998, there were considerably fewer visits to the plots for aphid control than in 1997 (9-10 vs 18-21) and a much higher proportion of the visits for aphid control resulted in a positive decision (91% vs 42%). It was thought that the larger proportion of positive decisions, particularly spray decisions, in 1998 may be partly a reflection of the larger numbers of aphids present, as well as the increased sample size. In 1999, although there was an even larger aphid infestation, more visits (9-15) were made to plots for aphid control, and only 65% resulted in a positive decision. However, many of the treatment thresholds had been reduced compared with those used in 1998. The proportion of 'no decisions' for caterpillars was still quite high in 1998-99, but this was possibly a reflection of the low infestation level (often close to the threshold level) and the subsequent application of small numbers of sprays.

In general, the relatively high number of 'no decisions' is likely to be a function of the sample size and the fact that samples of a fixed size were taken, rather than adopting a sequential sampling approach. In addition, the probabilities of making incorrect decisions (maximum probability of making an incorrect spray decision (alpha) = 0.75; maximum probability of making an incorrect no spray decision (beta) = 0.05) were chosen to minimise the risk of not spraying when pests were present. This 'risk averse' combination would itself increase the numbers of 'no decisions'. It is likely that increasing the sample size further, to have greater confidence in the decisions made, would increase the percentage of positive decisions ('spray' or 'no spray') and hence reduce the total numbers of visits required. If combined with a sequential sampling approach this would probably be more cost effective.

Costs of sampling

It takes approximately 2 hours to sample 40 mature plants in a Brussels sprout crop, exclusive of travelling time. Thus the sampling time spent in using systems such as those used in 1998 and 1999 would be about 20 hours/crop (Tables 4 & 5), if sampling for aphids and caterpillars was combined. Growers already walk their crops regularly and there is a strong argument for taking records in a consistent and statistically sound manner, both to justify the use of insecticides and to determine the risks attached to making certain decisions. At present, the costs of insecticide would be less than £10/ha for some of the products used. Spraying might cost about £10/ha (Nix, 1998). On an average crop of 4 ha (commercial fields sampled in 1996 – 1998 were between 1 and 7 ha), spraying with insecticides might therefore cost about £80 per occasion, although this would depend on whether a tank mix was used or not. There is the greatest scope for reducing the numbers of sprays targeted against caterpillars. However, at present these are usually relatively cheap and it is difficult to argue that they should be excluded on the grounds of cost. To err on the side of caution, growers may still wish to include them in a tank mix

CONCLUSIONS

- Intensive sampling during 1995-97 showed that, on average, plants at the edges of a brassica crop are more heavily infested with aphids and caterpillars than plants in the middle. In some fields there was considerable variation between different edges and/or corners in the numbers of plants infested with pests.
- If growers look at a very small number of plants then they may obtain a very poor estimate of the overall level of infestation and at very low levels of infestation they may have to look at a relatively large number of plants to detect aphid presence. The statistical techniques used in this project can be used to indicate the level of confidence growers can have in a particular sampling strategy. In the 1998 and 1999 trials, the sample size was increased from 25 to 40 plants to increase precision and the numbers of positive decisions.
- Cabbage aphid infested plants show a different spatial pattern to plants infested with caterpillars. Whereas caterpillar infested plants show strong clustering, aphid infestations do not appear to be clustered, with adjacent plants no more likely to be infested than for a random distribution. Patches of locally more dense aphid infestations are likely to some crop feature that makes the patch more suitable for aphid infestation. The lack of any strong spatial pattern for aphid infestations

suggests that a sampling scheme based on caterpillar spatial distribution should be used. The current recommendation is for sampled plants to be no closer than 10 plants apart to avoid over-sampling the same caterpillar infestation focus. Such a sampling scheme should also obtain a representative sample from the random distribution of aphid infested plants.

- In 1998 and 1999, treatment decisions about pest control within a 1ha plot at HRI Kirton were based on samples taken in rows 6-10 from the edge. At harvest, samples were taken from different locations within the plot, but there were no statistically significant differences in the aphid or caterpillar control at the different locations.
- Work within this project (and related projects) has identified a number of the key components of a practical supervised control protocol for growers. These are concerned mainly with where, when and how to sample crops to obtain reliable data. For the other elements of any scheme (sample size, treatment thresholds, decision-making systems, risks of incorrect decisions) some of the general trends have been discovered and presented. In practice, choices in these areas should made in light of the constraints associated with each individual situation.
- The timing of aphid immigration varies considerably from year to year, so that the date on which the first insecticide treatment is necessary will vary also. Late aphid immigration can lead to a significant reduction in the number of sprays applied during the season. Aphid colonisation occurred more than six weeks earlier in 1998 and 1999 than in 1997 and there was a consequent increase in the numbers of sprays applied.
- The 'Low' threshold treatment (threshold of 5% plants infested throughout the life of the crop) provided the most effective aphid control in 1998. There was no difference between treatments in 1999. Using a sample size of 40 plants and a threshold of 5%, crops are sprayed when 2 or more plants out of 40 are infested.
- During the study between 34 and 77% buttons in untreated plots were damaged by aphids at harvest. Depending on the supervised system used, levels of aphid control ranged from 60-90% compared with the untreated control plots. Even plots sprayed routinely (every 2 weeks) in 1997 and 1998 suffered 3-4% infestation with aphids (88-95% control). In both years, there was at least one supervised treatment which produced levels of control that were not statistically significantly different from the control sprayed routinely, with fewer or the same number of sprays.
- There is a clear relationship between the numbers of sprays (OP/carbamate/pyrethroid) applied to control aphids and the effectiveness of the spray programme when compared with the untreated control plots. Extrapolation from the fitted equation indicates that using this range of insecticides, approximately 18 sprays would have to be applied to a crop to achieve 90% control. Thus on a crop where 50% buttons would be infested in the absence of insecticide treatment, 18 sprays would be expected to leave 5% of buttons infested at harvest. Obviously, in years when infestations are low, acceptable levels of control could be achieved with fewer sprays. However, in years of heavy infestation it would not be possible to achieve acceptable levels of control without the application of large numbers of sprays.
- There is evidence from this project and projects FV 208 and FV 208a that effective aphid control can be achieved with lower numbers of insecticide sprays if the seed is film-coated with imidacloprid (Gaucho), or triazamate is used as a foliar spray. Both insecticide treatments have been submitted to PSD for approval

(full or specific off-label).

- During the study between 1 and 19% buttons in untreated plots were damaged by caterpillars at harvest. In years when the period of caterpillar infestation was discrete it was possible to control caterpillars with small numbers of targeted sprays, using a supervised system. LINK Project FV 163 showed that targeted sprays of *Bacillus thuringiensis* could achieve effective control of diamond-back moth and small white butterfly caterpillars.
- In 1999, when infestations were light, a maximum of 4 sprays was applied to control caterpillars on the supervised plots. Depending on the supervised system used, levels of caterpillar control ranged from 20-100% compared with the untreated control plots.
- Aphid and caterpillar damage was most severe on buttons on the lower part of the stem. Even plots treated routinely with insecticides suffered some pest damage and this was probably due to the inaccessibility of the lower buttons to insecticides. The overall amount of damage can be reduced by discarding the buttons on the lowest part of the stem.
- Although there is a nil tolerance for pest damage on harvested Brussels sprouts, in reality it is very difficult to achieve 100% control of aphids on commercial crops even with the application of large numbers of sprays. This is partly due to the inaccessibility of aphids to insecticides and also to the relative ineffectiveness of the insecticides Approved currently. In the small plot trials at HRI Kirton, the levels of aphid infestation achieved with the best supervised programme were generally about 7%. However, this is based on assessment of all the buttons on the stem (including those at the base of the stem) and very careful examination of each button (under the wing leaves).

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Table 1 Summary of visits to make decisions, number of 'No decisions' and spray decisions made for each treatment.

Aphid control

Treatment	Insecticides applied	Thresholds	Number of visits	Number of 'No decisions'	Number of sprays applied
A	Dimethoate, pirimicarb	5,5,5	9	0.7	8.3
A - Large plot	Dimethoate, pirimicarb	5,5,5	9	0	9
B	Imidacloprid, dimethoate, pirimicarb	5,5,5	11	2	9
C	Imidacloprid, triazamate	5,5,5	13	6	7
D	Imidacloprid, triazamate	10,5,5	15	7.7	5.7
E	Imidacloprid, triazamate	20,5,5	13.3	5	5.3

Caterpillar control

Treatment	Insecticide applied	Thresholds	Number of visits	Number of 'No decisions'	Number of sprays applied
A	Deltamethrin	5,5,5	11.3	7.7	2
A - Large plot	Deltamethrin	5,5,5	11.0	6	4
B	Deltamethrin	5,5,5	11.0	8.0	1.7
C	Deltamethrin	5,5,5	12.3	10.0	1.3
D	Deltamethrin	10,5,5	9.0	2.7	1.7
E	Deltamethrin	20,5,5	10.3	3.7	1

Table 2a Analysis of data from the small plot trial at HRI Kirton – total weight and total number of buttons harvested (30 stems). Values shown are treatment means.

Treatment	**Total weight (g)**	*Transformed values*	**Total number**	*Transformed values*
A	4878	*8.492*	634.9	*25.2*
B	5124	*8.542*	642.5	*25.36*
C	5452	*8.604*	652.7	*25.55*
D	5241	*8.564*	630.2	*25.11*
E	5046	*8.527*	607.1	*24.65*
Wald Statistic (4 df)		*2.1*		*3.2*
Significance level		*NS*		*NS*
SED (4 df)		*0.82*		*0.557*
LSD (5%)		2.276		1.546

Height	**Total weight**	*Transformed values*	**Total No.**	*Transformed values*
Top	3237	*8.082*	674.5	*25.98*
Middle	6366	*8.759*	596.6	*24.43*
Bottom	6608	*8.796*	630.3	*25.11*
Wald Statistic (2 df)		*380.3*		*15.2*
Significance level		*P<0.001*		*p<0.001*
SED (20 df)		*0.04119*		*0.397*
LSD (5%)		0.086		0.828

Table2b Analysis of data from the small plot trial at HRI Kirton – percentage of buttons damaged (by weight). Values shown are treatment means.

Treatment	**Undamaged**	**Caterpillar**	**Aphid**	**Slug**	**Non-pest**
A	59.42	1.12	16.36	13.57	0.74
B	58.39	1.35	13.55	19.06	0.72
C	55.03	1.43	14.04	14.9	0.95
D	64.23	0.53	14.76	11.38	0.62
E	63.53	1.25	7.58	15.02	0.90
Wald Statistic (4 df)	*19*	*2.5*	*2.8*	*3.3*	*0.6*
Significance level	*P<0.001*	*NS*	*NS*	*NS*	*NS*
SED (4 df)	*2.508*	*0.663*	*5.777*	*4.621*	*0.493*
LSD (5%)	6.962	1.840	16.037	12.828	1.368

Height	**Undamaged**	**Caterpillar**	**Aphid**	**Slug**	**Non-pest**
Top	87.93	0.437	3.36	4	0.388
Middle	56.13	0.927	15.11	14.73	0.6369
Bottom	36.3	2.04	21.3	25.63	1.3226
Wald Statistic (2 df)	*889*	*12*	*60.4*	*147.5*	*7.4*
Significance level	*P<0.001*	*P<0.01*	*P<0.001*	*P<0.001*	*P<0.05*
SED (20 df)	*1.747*	*0.475*	*2.344*	*1.782*	*0.357*
LSD (5%)	3.644	0.991	4.890	3.717	0.745

Table 2c Analysis of data from the small plot trial at HRI Kirton – percentage of buttons damaged (by number). Values shown are treatment means.

Treatment	Undamaged	Caterpillar	Aphid	Slug	Non-pest
A	61.41	1.128	14.88	13.6	0.7614
B	61.73	1.343	11.95	17.73	0.7495
C	59.18	1.466	12.56	14.43	0.958
D	67.29	0.719	12.56	11.11	0.7946
E	67.05	1.302	6.21	14.23	0.9475
Wald Statistic (4 df)	*15.1 (4)*	*1.3*	*2.6*	*2.7*	*0.3*
Significance level	*P<0.01*	*NS*	*NS*	*NS*	*NS*
SED (4 df)	*2.643*	*0.7439*	*5.708*	*4.318*	*0.5707*
LSD (5%)	7.337	2.065	15.845	11.987	1.584

Height	Undamaged	Caterpillar	Aphid	Slug	Non-pest
Top	90.72	0.345	2.77	3	0.3069
Middle	60.67	0.847	12.86	13.26	0.5821
Bottom	38.6	2.382	19.26	26.4	1.6376
Wald Statistic (2 df)	*807.6*	*15.6*	*55.5*	*166.7*	*11.3*
Significance level	*P<0.001*	*P<0.001*	*P<0.001*	*P<0.001*	*P<0.01*
SED (20 df)	*1.841*	*0.5379*	*2.231*	*1.817*	*0.4177*
LSD (5%)	3.840	1.122	4.654	3.790	0.871

Table 3a Comparison of data from the large and small plot trials at HRI Kirton. Significance of treatment effects within nested treatment structure (effects significant at the nominal 0.05, 0.01 and 0.001 levels are shown).

	Percentage by number				
	Undamaged	**Caterpillar**	**Aphid**	**Slug**	**Non-pest**
Treated vs untreated	*<0.001*		*<0.001*	*<0.01*	
Small plots vs large plot (supervised)			*<0.05*	*<0.01*	
Cereal edge vs others (large plot)					
Grass vs road vs copse edges (large plot)				*<0.05*	
Edge vs part-way into crop vs middle (large plot)					
Height on stem	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*0.001*
Treated vs untreated vs height	*<0.001*		*<0.05*	*<0.05*	
Small plots vs large plot vs height (supervised)	*<0.05*		*<0.05*	*<0.001*	
Cereal edge vs others vs height (large plot)					
Grass vs road vs copse edges vs height (large plot)				*<0.05*	
Edge vs part-way into crop vs middle vs height (large plot)					

	Percentage by weight				
	Undamaged	**Caterpillar**	**Aphid**	**Slug**	**Non-pest**
Treated vs untreated	*<0.001*		*<0.001*	*<0.01*	
Small plots vs large plot (supervised)			*<0.05*	*<0.01*	
Cereal edge vs others (large plot)					
Grass vs road vs copse edges (large plot)					
Edge vs part-way into crop vs middle (large plot)					
Height on stem	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.05*
Treated vs untreated vs height	*<0.001*		*<0.05*	*<0.05*	
Small plots vs large plot vs height (supervised)	*<0.05*			*<0.001*	
Cereal edge vs others vs height (large plot)					
Grass vs road vs copse edges vs height (large plot)				*<0.05*	
Edge vs part-way into crop vs middle vs height (large plot)					

Table 3b Comparison of data from the large and small plot trials at HRI Kirton – total weight and total number of buttons harvested (30 stems). Values shown are treatment means.

Location	Total weight (g)	*Transformed values*	Total No.	*Transformed values*
Untreated plot	5646	*8.639*	757.0	*27.52*
Supervised plots	5004	*8.518*	672.0	*25.93*
Small plots	4878	*8.492*	642.1	*25.35*
Large plot	5039	*8.525*	681.4	*26.11*
Cereal	5907	*8.684*	683.0	*26.14*
Grass	5625	*8.635*	716.9	*26.78*
Road	4459	*8.403*	675.0	*25.99*
Copse	4838	*8.484*	652.1	*25.54*
Edge	4550	*8.336*	660.4	*25.56*
Intermediate	5237	*8.564*	701.7	*26.50*
Middle	5556	*8.623*	689.1	*26.26*
Comparison between untreated and supervised treatments				
SED (6 d.f.)		*0.179*		1.264
LSD (5%)		*0.437*		*3.093*
Comparison between small and large plots				
SED		*0.113*		0.802
LSD (5%)		*0.277*		*1.962*
Comparison between cereals edge and other edges				
SED (6 d.f.)		*0.199*		1.406
LSD (5%)		*0.486*		*3.440*
Comparison between other edges and between distances from edge				
SED		*0.141*		0.994
LSD (5%)		*0.344*		*2.432*
Height	**Total weight**	***Transformed values***	**Total No.**	***Transformed values***
Top	3253	*8.087*	712.70	*26.7*
Middle	5811	*8.668*	605.00	*24.6*
Bottom	6793	*8.824*	719.50	*26.83*
SED (12 d.f.)		*0.042*		*0.335*
LSD (5%)		*0.092*		*0.730*

Table 3c Comparison of data from the large and small plot trials at HRI Kirton – percentage damaged buttons (by weight). Values shown are treatment means.

Treatment	**Undamaged**			**Caterpillar**			**Aphid**			**Slug**		
Untreated plot	2.44			0.54			79.30			62.31		
Supervised plots	54.46			1.52			10.99			27.29		
Small plots		58.92			0.99			16.96			14.02	
Large plot		53.12			1.68			9.21			31.27	
Cereal			53.74			1.70			13.10			28.20
Grass			48.45			2.18			12.38			36.83
Road			53.42			1.72			5.70			35.70
Copse			57.29			1.12			8.24			22.30
Edge			48.65			1.76			8.74			37.46
Intermediate			58.64			0.89			7.66			24.43
Middle			51.89			2.37			9.92			32.94
Comparison between untreated and supervised treatments												
SED (6 d.f.)	*4.490*			*0.866*			*4.952*			*6.998*		
LSD (5%)	*10.987*			*2.119*			*12.117*			*17.124*		
Comparison between small and large plots												
SED (6 d.f.)		*2.848*			*0.549*			*3.141*			*4.439*	
LSD (5%)		*6.969*			*1.343*			*7.686*			*10.862*	
Comparison between cereals edge and other edges												
SED (6 d.f.)			*4.996*			*0.964*			*5.510*			*7.786*
LSD (5%)			*12.225*			*2.359*			*13.482*			*19.052*
Comparison between other edges and between distances from edge												
SED (6 d.f.)			*3.532*			*0.681*			*3.896*			*5.506*
LSD (5%)			*8.642*			*1.666*			*9.533*			*13.473*
Height		**Undamaged**			**Caterpillar**			**Aphid**			**Slug**	
Top		79.95			0.49			10.39			8.04	
Middle		48.78			1.04			16.48			29.02	
Bottom		23.51			2.82			20.76			52.32	
SED (12 d.f.)		*1.661*			*0.389*			*1.411*			*1.882*	
LSD (5%)		*3.619*			*0.848*			*3.074*			*4.101*	

Table 3d Comparison of data from the large and small plot trials at HRI Kirton – percentage damaged buttons (by number). Values shown are treatment means.

Location	Undamaged			Caterpillar			Aphid			Slug		
Untreated plot	3.59			0.67			76.71			56.87		
Supervised plots	57.03			1.63			9.79			26.23		
Small plots		61.05			1.04			15.40			13.89	
Large plot		55.83			1.81			8.11			29.94	
Cereal			56.54			1.65			11.79			26.11
Grass			50.63			2.49			10.48			36.11
Road			55.69			1.68			5.20			34.60
Copse			60.92			1.30			7.41			20.38
Edge			52.26			1.68			7.13			35.42
Intermediate			61.33			1.15			7.01			23.10
Middle			53.66			2.65			8.95			32.56
Comparison between untreated and supervised treatments												
SED (6 d.f.)	*4.154*			*0.936*			*4.604*			*6.150*		
LSD (5%)	*10.164*			*2.290*			*11.266*			*15.049*		
Comparison between small and large plots												
SED (6 d.f.)		*2.635*			*0.594*			*2.92*			*3.901*	
LSD (5%)		*6.448*			*1.453*			*7.145*			*9.545*	
Comparison between cereals edge and other edges												
SED (6 d.f.)			*4.622*			*1.042*			*5.122*			*6.843*
LSD (5%)			*11.310*			*2.550*			*12.533*			*16.744*
Comparison between other edges and between distances from edge												
SED (6 d.f.)			*3.269*			*0.737*			*3.622*			*4.838*
LSD (5%)			*7.999*			*1.803*			*8.863*			*11.838*

Height	Undamaged	Caterpillar	Aphid	Slug
Top	82.10	0.36	10.48	6.01
Middle	52.36	1.05	14.46	27.21
Bottom	25.19	3.28	18.77	52.05
SED (12 d.f.)	*1.711*	*0.437*	*1.219*	*2.046*
LSD (5%)	*3.728*	*0.952*	*2.656*	*4.458*

Table 4 Aphid control - summary of treatments applied, decisions made and percentage control achieved in 1997-99.

		Treatment	Thresholds	Number of visits	Number of 'No decisions'	Number of sprays	% infested with aphids	% infested with aphids (untreated plots)	% control vs untreated
1997	Routine	Pirimicarb/DSM/heptenophos	None	None	None	11	4.0	34	88.2
	M1	Pirimicarb + heptenophos when <15°C	20,10,5	18	9.7	3.3	7.0	34	79.4
	M2	DSM/nicotine before crash, pirmicarb/nicotine after	20,10,5	21	13.7	2.3	14.0	34	58.8
	M3	Pirimicarb before crash, DSM after crash	20,10,5	19.3	11.3	3	14.0	34	58.8
	M4	DSM/nicotine before crash, pirimicarb/nicotine after	20,10,5	18.7	7.3	6	3.0	13	76.9
	M5	Pirimicarb before crash, DSM after crash	20,10,5	18.7	8	6	2.0	13	84.6
	Grower	DSM, cypermethrin, triazophos				4	0.2	None	
1998	Routine	Alternate between pirimicarb and DSM	None	None	None	9	2.8	58.0	95.2
	B	Alternate between pirimicarb and DSM	10,5,5	9.7	1.3	8.3	12.9	58.0	77.8
	C	Alternate between pirimicarb and DSM	20,10,5	9.3	0.3	6.7	15.0	58.0	74.1
	D	Alternate between pirimicarb and DSM	5,5,5	9	0.7	8.3	7.5	58.0	87.1
	E	Alternate between pirimicarb and DSM	20,10,5	10	0.7	6.7	10.6	58.0	81.7
	Large plot	Alternate between pirimicarb and DSM	10,5,5	10	1	8	6.9	58.0	88.1
	BM	Alternate between pirimicarb and DSM	10,5,5	8	0	6	0.4	None	
	Grower						0.4		
	BY	Alternate between pirimicarb and DSM	10,5,5	8	0	7	0.2	None	
	Grower	Pirimicarb, DSM, cypermethrin, lambda-cyhalothrin				6	0.4	None	
	FR	Alternate between pirimicarb and DSM	10,5,5	9	1	6	0.8	None	
	Grower	Dimethoate, cypermethrin				4	22.3	None	
	HN	Alternate between pirimicarb and DSM	10,5,5	9	1	6	6.6	None	
	Grower	Dimethoate, cypermethrin				7	15.7	None	
1999	A	Dimethoate, pirimicarb	5,5,5	9	0.7	8.3	15.0	76.7	80.4
	Large plot	Dimethoate, pirimicarb	5,5,5	9	0	9	8.1	76.7	89.4
	B	Imidacloprid, dimethoate, pirimicarb	5,5,5	11	2	9	10.6	76.7	86.2
	C	Imidacloprid, triazamate	5,5,5	13	6	7	12.1	76.7	84.2
	D	Imidacloprid, triazamate	10,5,5	15	7.7	5.7	12.0	76.7	84.4
	E	Imidacloprid, triazamate	20,5,5	13.3	5	5.3	6.9	76.7	91.0

Table 5 Caterpillar control - summary of treatments applied, decisions made and percentage control achieved in 1997-99.

	Treatment	Thresholds	Number of visits	Number of 'No decisions'	No. pyrethroid sprays	No. Bt sprays	% infested with caterpillars	% infested with caterpillars (untreated plots)	% control vs untreated
1997	Routine	None	None		11		7	19	63.2
	M1	40,10,5	19	11	0	3	13	19	31.6
	M2	40,10,5	18.7	11.3	0	2.3	15	19	21.1
	M3	40,10,5	20	13	0	2	15	19	21.1
	M4	40,10,5	19	9.6	1	3.3	13	23	43.5
	M5	40,10,5	19	10.7	1	4	10	23	56.5
	Grower				5		6.5	None	
1998	Routine	None			9		1	6.8	85.3
	B	10,5,5	12	6.7	3.7		1.6	6.8	76.5
	C	40,10,5	12	4.7	2		2.2	6.8	67.6
	D	5,5,5	13	6	3		1.8	6.8	73.5
	E	40,10,5	12.7	5.7	1.3		1.7	6.8	75.0
	Large plot	10,5,5	13	7	4		0.4	6.8	94.1
	BM	10,5,5	12	9	3		0.9	None	
	Grower						2.9		
	BY	10,5,5	11	5	2		0.6	None	
	Grower				7		0.8	None	
	FR	10,5,5	11	6	2		0.2	None	
	Grower				5		2.2	None	
	HN	10,5,5	9	3	5		18	None	
	Grower				7		20.4	None	
1999	A	5,5,5	11.3	7.7	2		1.1	0.7	100.0
	Large plot	5,5,5	11	6	4		1.8	0.7	100.0
	B	5,5,5	11.0	8.0	1.7		1.3	0.7	100.0
	C	5,5,5	12.3	10.0	1.3		1.5	0.7	100.0
	D	10,5,5	9.0	2.7	1.7		0.7	0.7	100.0
	E	20,5,5	10.3	3.7	1		1.3	0.7	100.0

Figure 1. Plan of large plot at HRI Kirton showing areas from which harvest samples were taken. N.B. Grey bars are pathways.

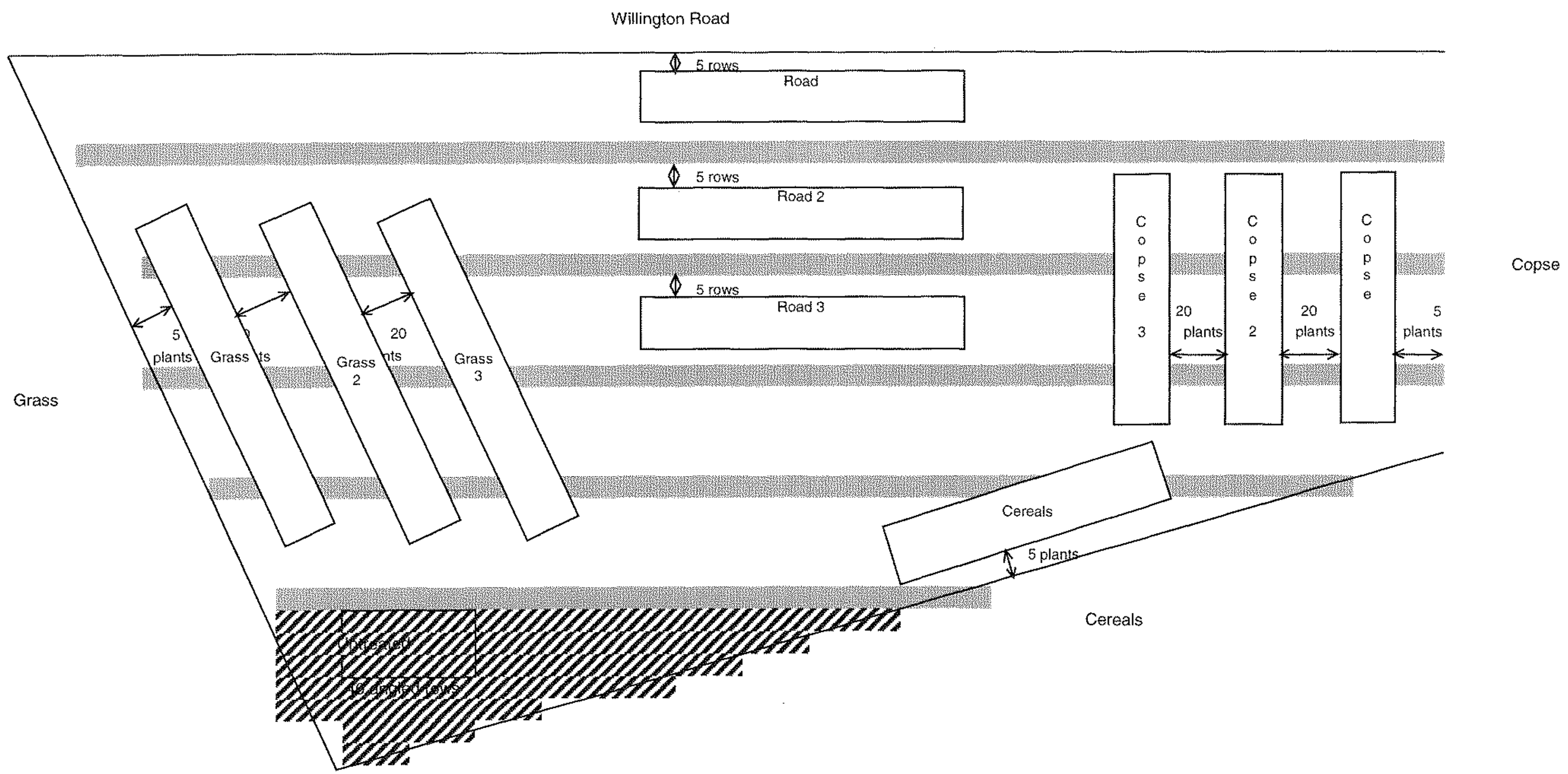


Figure 2. Mean numbers of cabbage aphid colonies on 20 insecticide-free Brussels sprout plants at five sites in South Lincolnshire in 1999 (data from HRI Kirton Pest Monitoring Service).

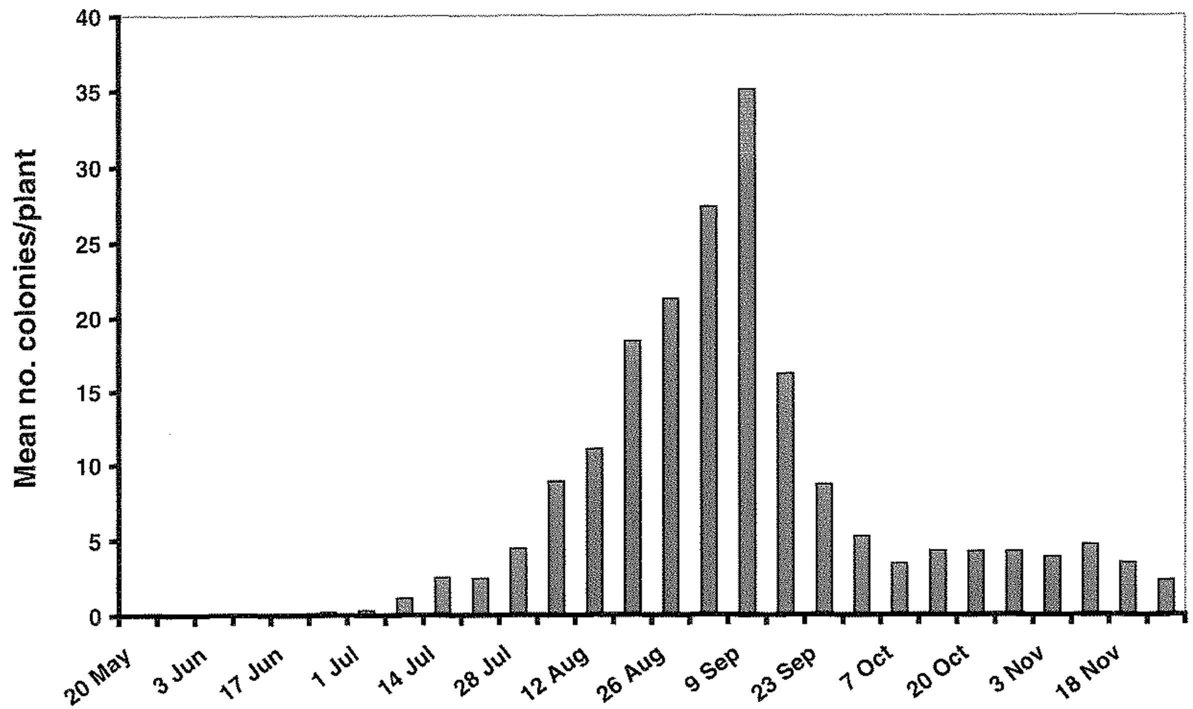


Figure 3. Mean numbers of diamond-back moth caterpillars on 20 insecticide-free Brussels sprout plants at five sites in South Lincolnshire in 1999 (data from HRI Kirton Pest Monitoring Service).

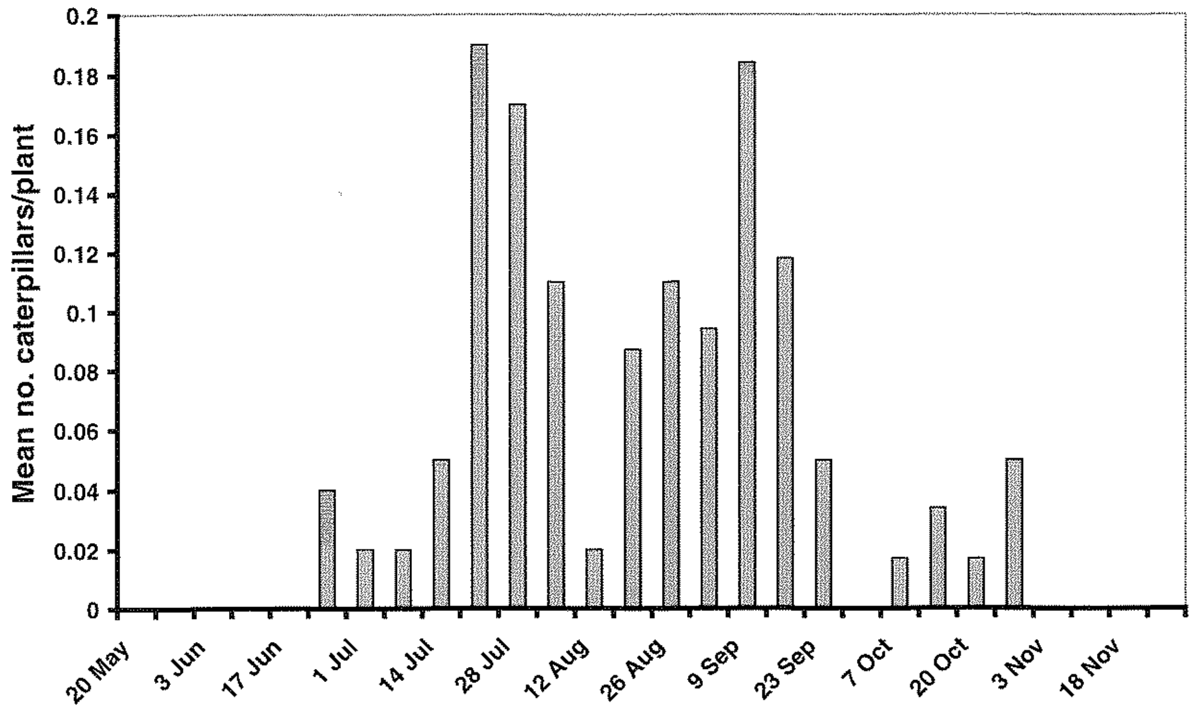


Figure 4. Mean numbers of small white butterfly caterpillars on 20 insecticide-free Brussels sprout plants at five sites in South Lincolnshire in 1999 (data from HRI Kirton Pest Monitoring Service).

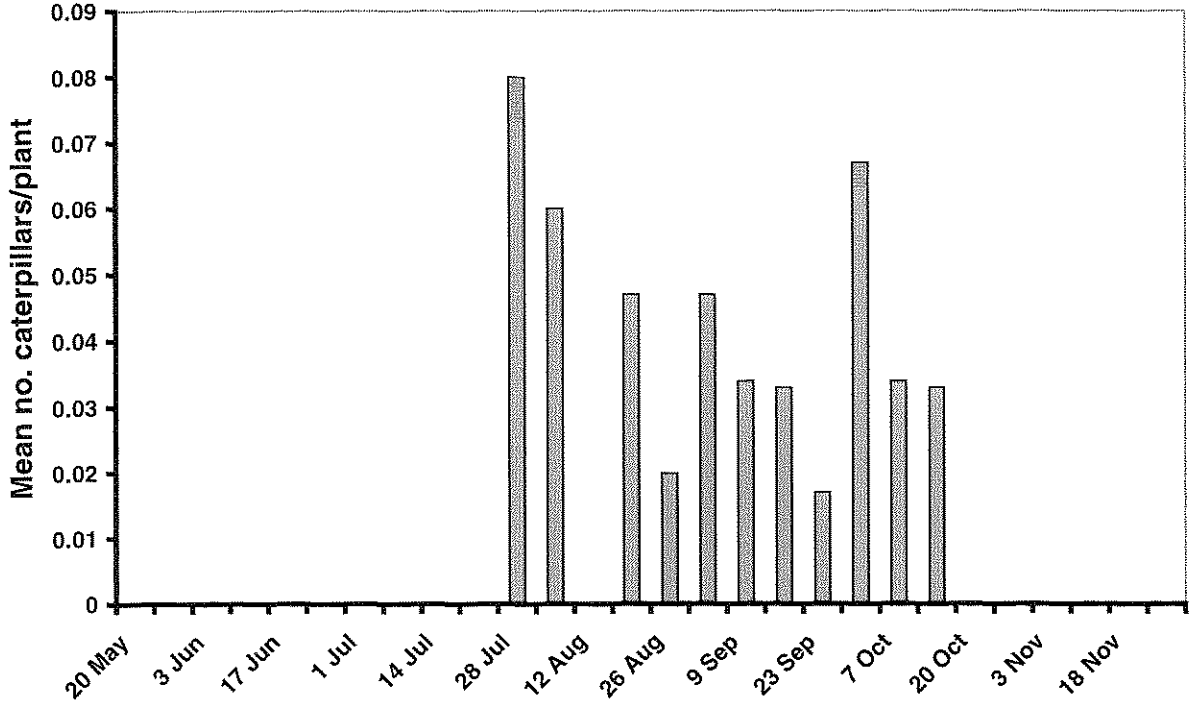


Figure 5a. The numbers of Brussels sprout plants infested with cabbage aphids at HRI Kirton in 1999. Forty plants were sampled on each occasion. Each replicate is shown separately. Treatment A (untreated seed and foliar sprays of pirimicarb and dimethoate). Treatment threshold of 5%. Spots show dates when 'spray' decisions made. Separate lines are shown for each of the three replicate plots.

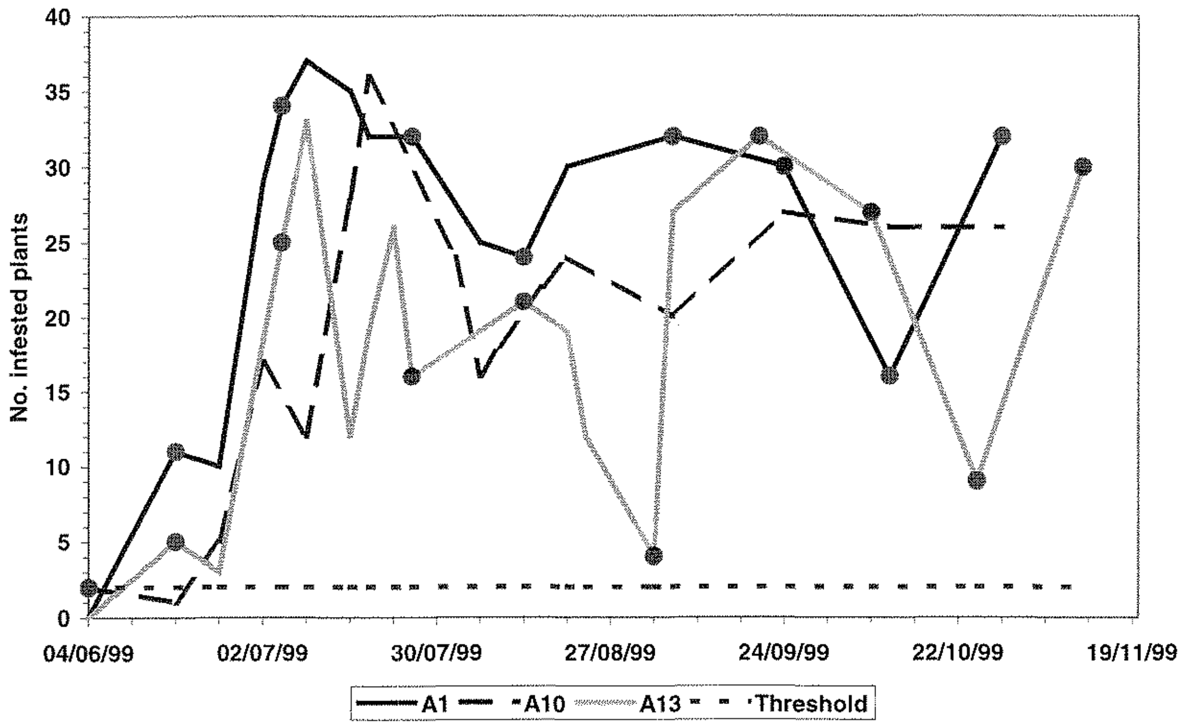


Figure 5b. The numbers of Brussels sprout plants infested with cabbage aphids at HRI Kirton in 1999. Forty plants were sampled on each occasion. Each replicate is shown separately. Treatment B (seed treated with imidacloprid and foliar sprays of pirimicarb and dimethoate). Treatment threshold of 5%. Spots show dates when 'spray' decisions made. Separate lines are shown for each of the three replicate plots.

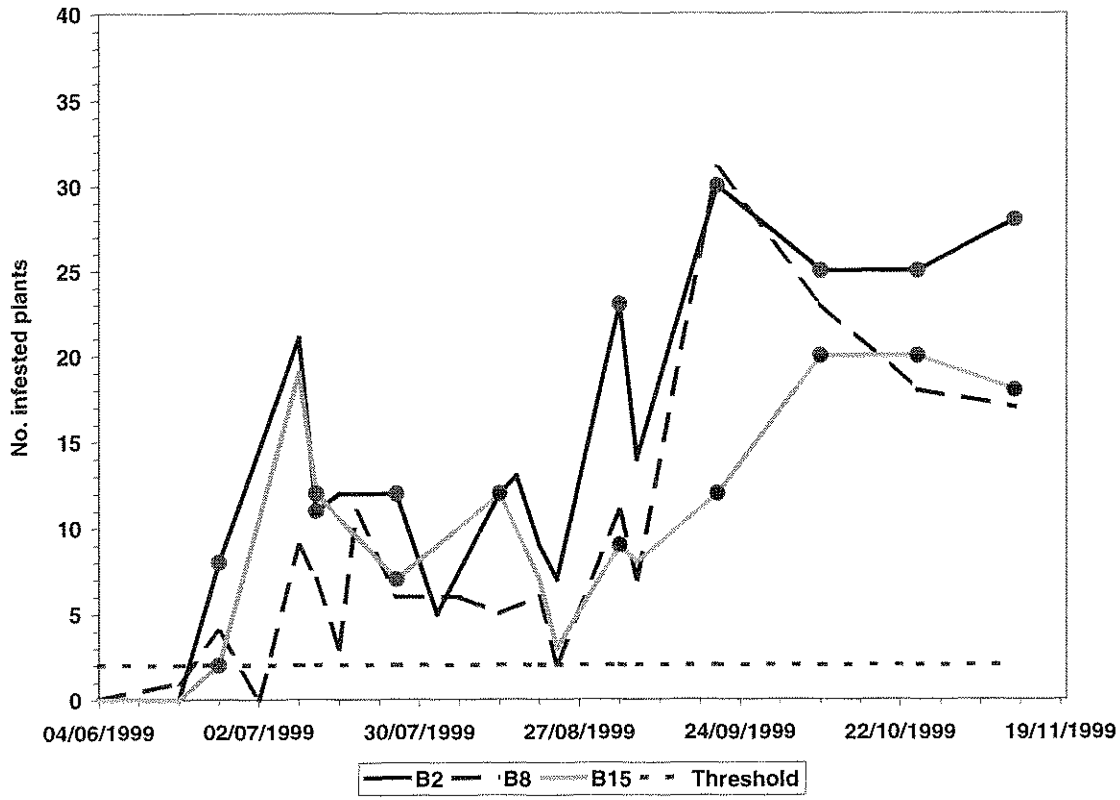


Figure 5c. The numbers of Brussels sprout plants infested with cabbage aphids at HRI Kirton in 1999. Forty plants were sampled on each occasion. Each replicate is shown separately. Treatment C (seed treated with imidacloprid and foliar sprays of triazamate). Treatment threshold of 5%. Spots show dates when 'spray' decisions made. Separate lines are shown for each of the three replicate plots.

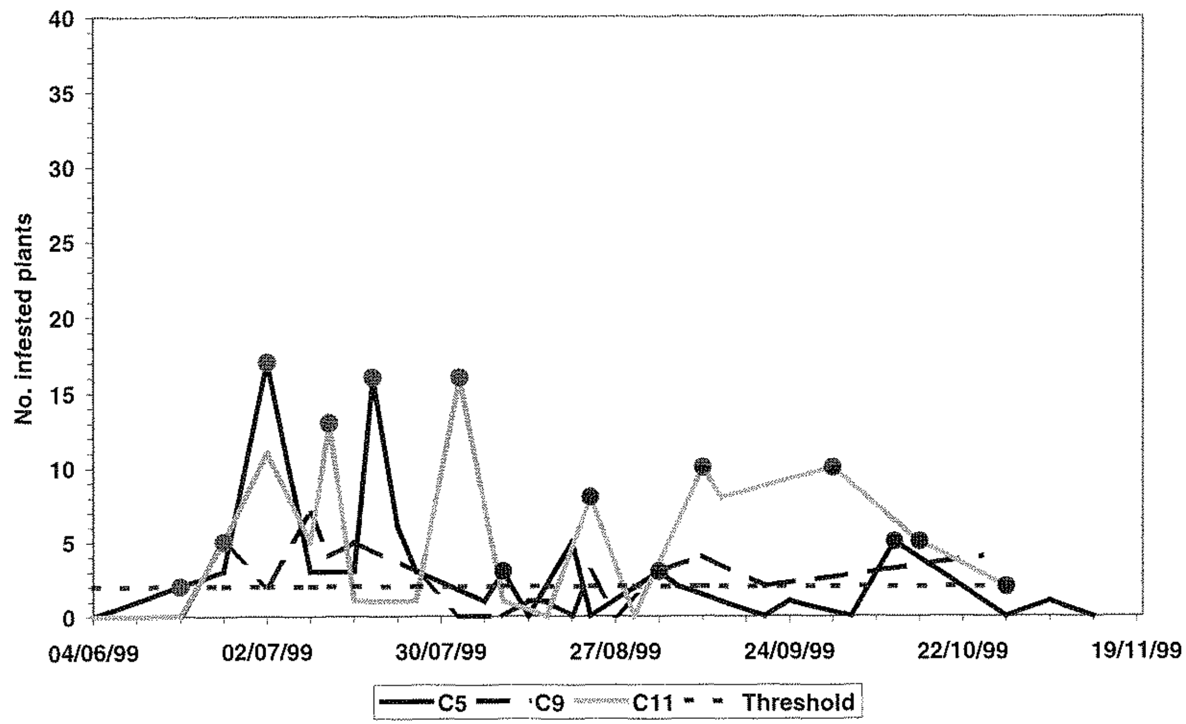


Figure 5d. The numbers of Brussels sprout plants infested with cabbage aphids at HRI Kirton in 1999. Forty plants were sampled on each occasion. Each replicate is shown separately. Treatment D (seed treated with imidacloprid and foliar sprays of triazamate). Treatment thresholds of 10 and 5%. Spots show dates when 'spray' decisions made. Separate lines are shown for each of the three replicate plots.

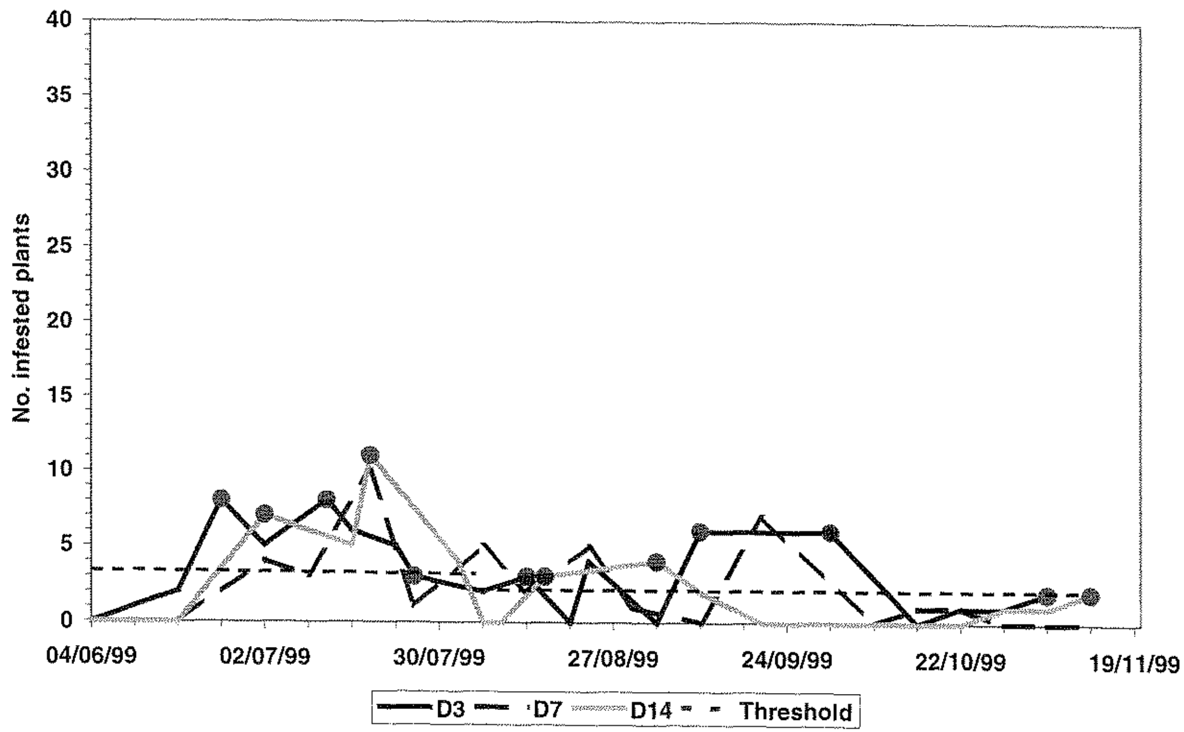


Figure 5e. The numbers of Brussels sprout plants infested with cabbage aphids at HRI Kirton in 1999. Forty plants were sampled on each occasion. Each replicate is shown separately. Treatment E (seed treated with imidacloprid and foliar sprays of triazamate). Treatment thresholds of 20 and 5%. Spots show dates when 'spray' decisions made. Separate lines are shown for each of the three replicate plots.

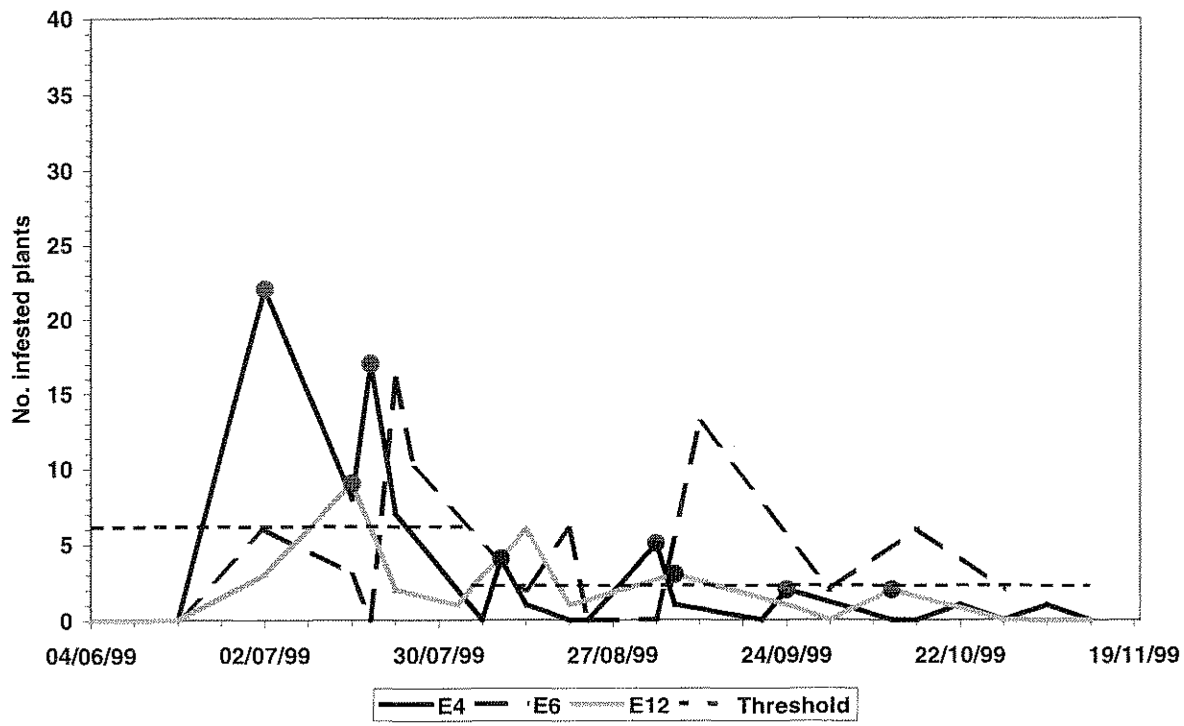


Figure 6a. The numbers of Brussels sprout plants infested with caterpillars at HRI Kirton in 1999. Forty plants were sampled on each occasion. Each replicate is shown separately. Treatment A Treatment threshold of 5%. Spots show dates when 'spray' decisions made. Separate lines are shown for each of the three replicate plots.

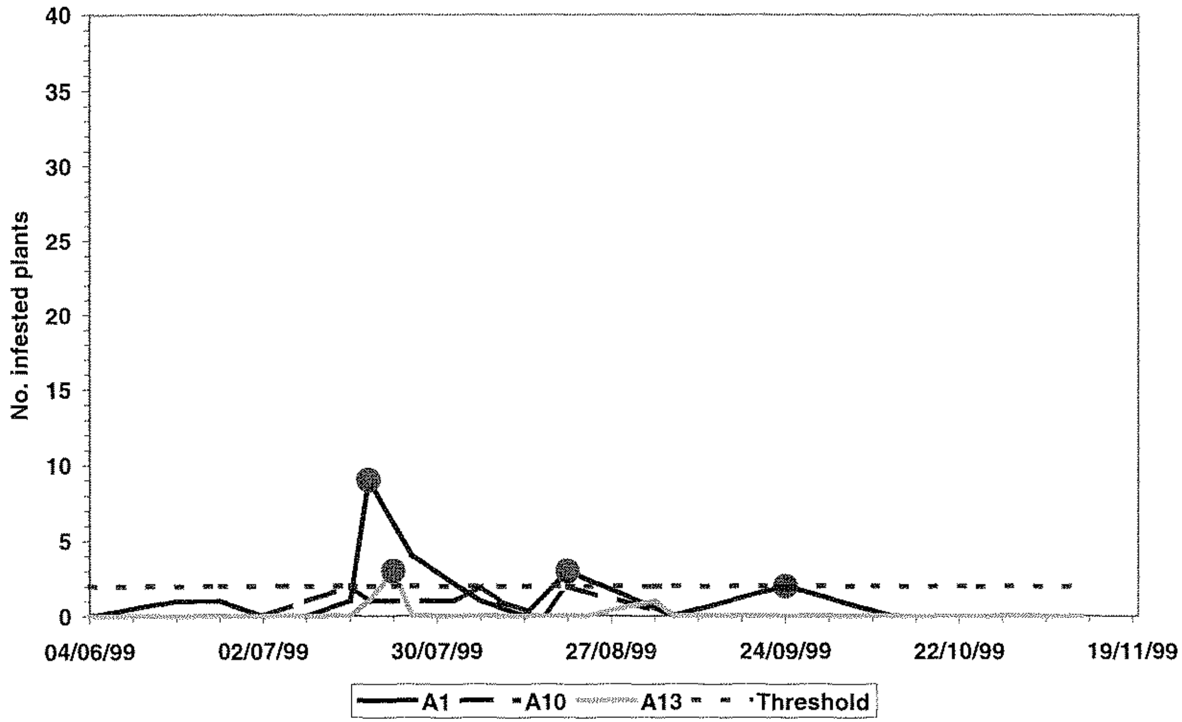


Figure 6b. The numbers of Brussels sprout plants infested with caterpillars at HRI Kirton in 1999. Forty plants were sampled on each occasion. Each replicate is shown separately. Treatment B. Treatment threshold of 5%. Spots show dates when 'spray' decisions made. Separate lines are shown for each of the three replicate plots.

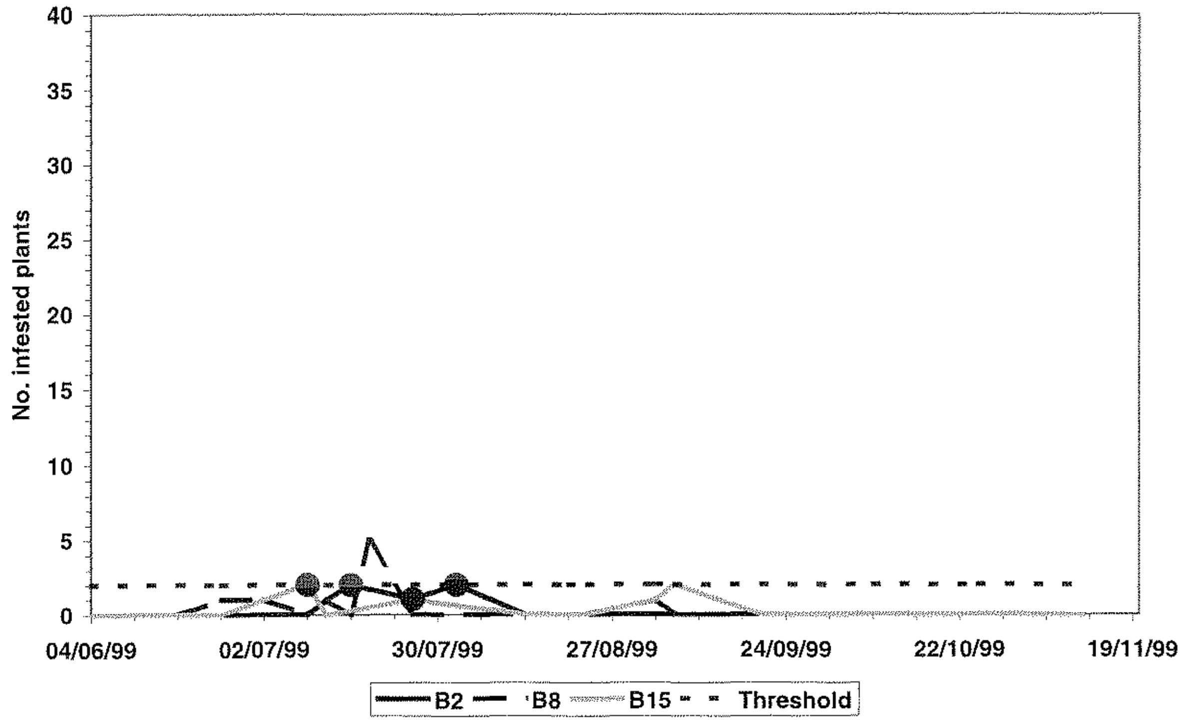


Figure 6c. The numbers of Brussels sprout plants infested with caterpillars at HRI Kirton in 1999. Forty plants were sampled on each occasion. Each replicate is shown separately. Treatment C. Treatment threshold of 5%. Spots show dates when 'spray' decisions made. Separate lines are shown for each of the three replicate plots.

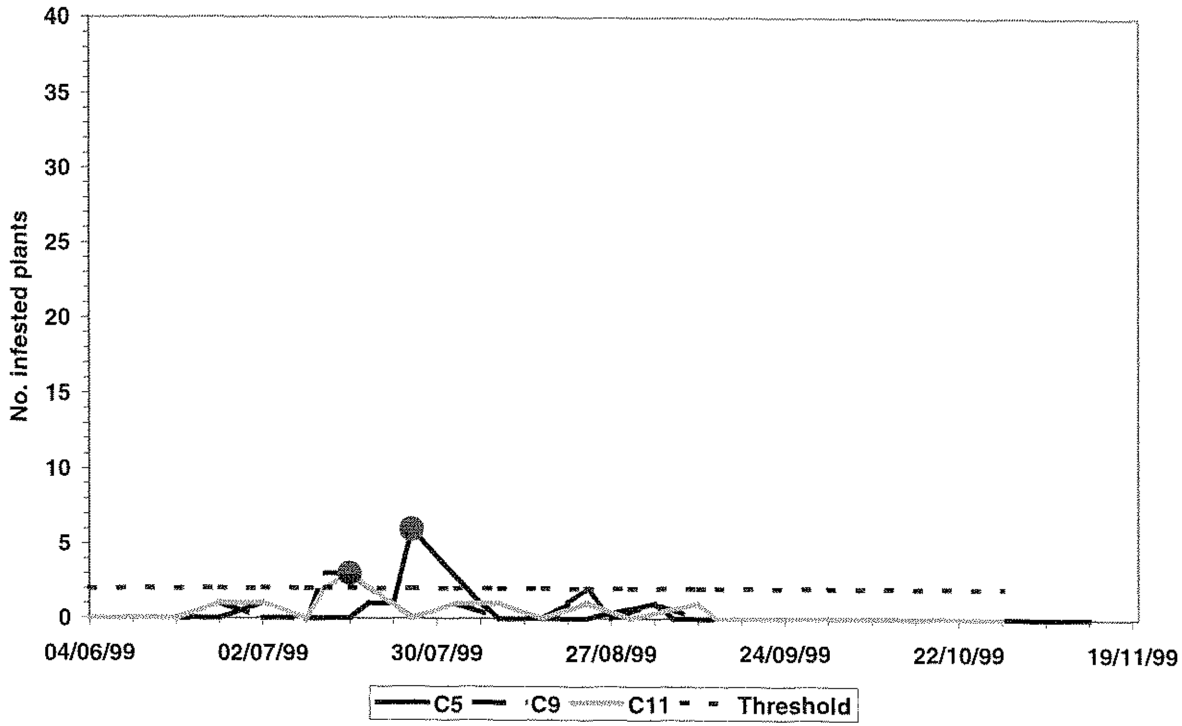


Figure 6d. The numbers of Brussels sprout plants infested with caterpillars at HRI Kirton in 1999. Forty plants were sampled on each occasion. Each replicate is shown separately. Treatment D. Treatment thresholds of 10 and 5%. Spots show dates when 'spray' decisions made. Separate lines are shown for each of the three replicate plots.

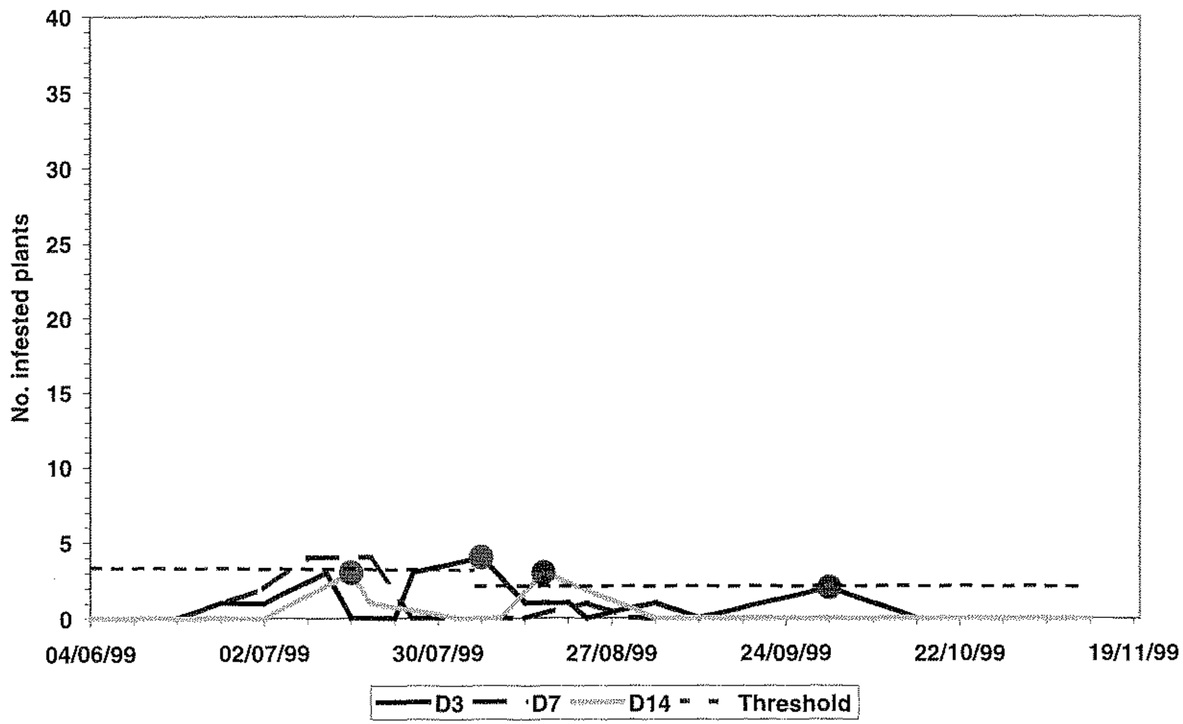


Figure 6e. The numbers of Brussels sprout plants infested with caterpillars at HRI Kirton in 1999. Forty plants were sampled on each occasion. Each replicate is shown separately. Treatment E. Treatment thresholds of 20 and 5%. Spots show dates when 'spray' decisions made. Separate lines are shown for each of the three replicate plots.

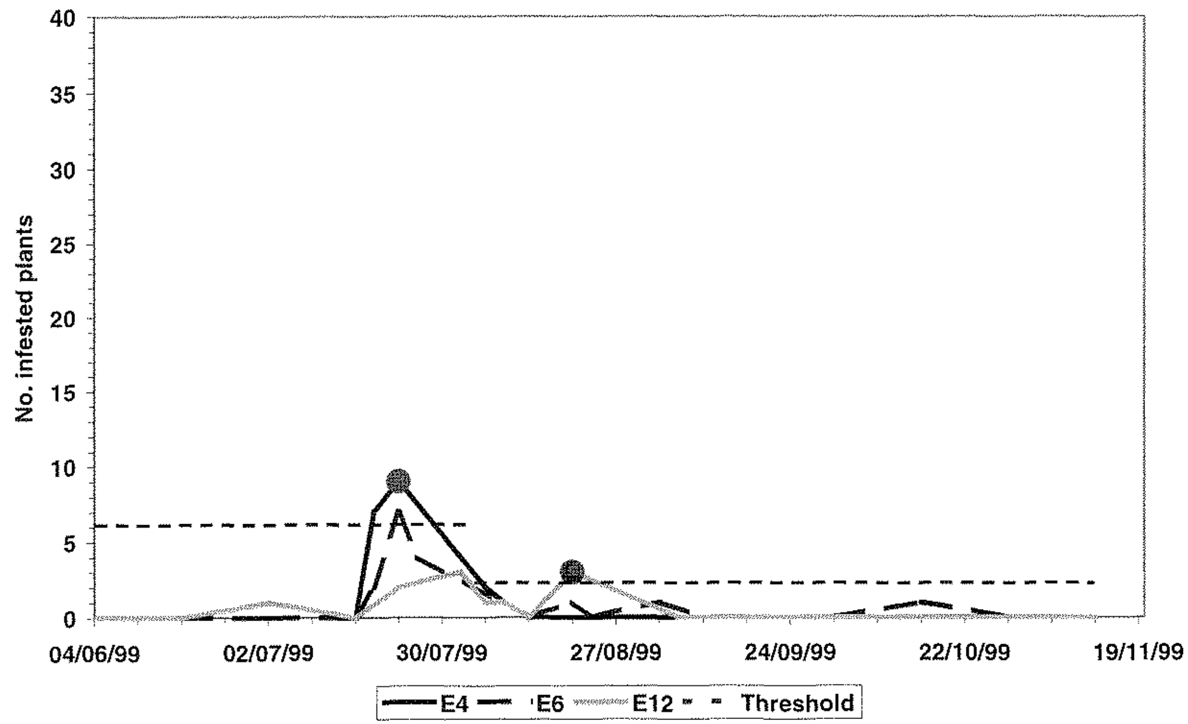


Figure 7. The numbers of Brussels sprout plants infested with cabbage aphids in the large plot at HRI Kirton in 1999. Forty plants were sampled on each edge on each occasion.

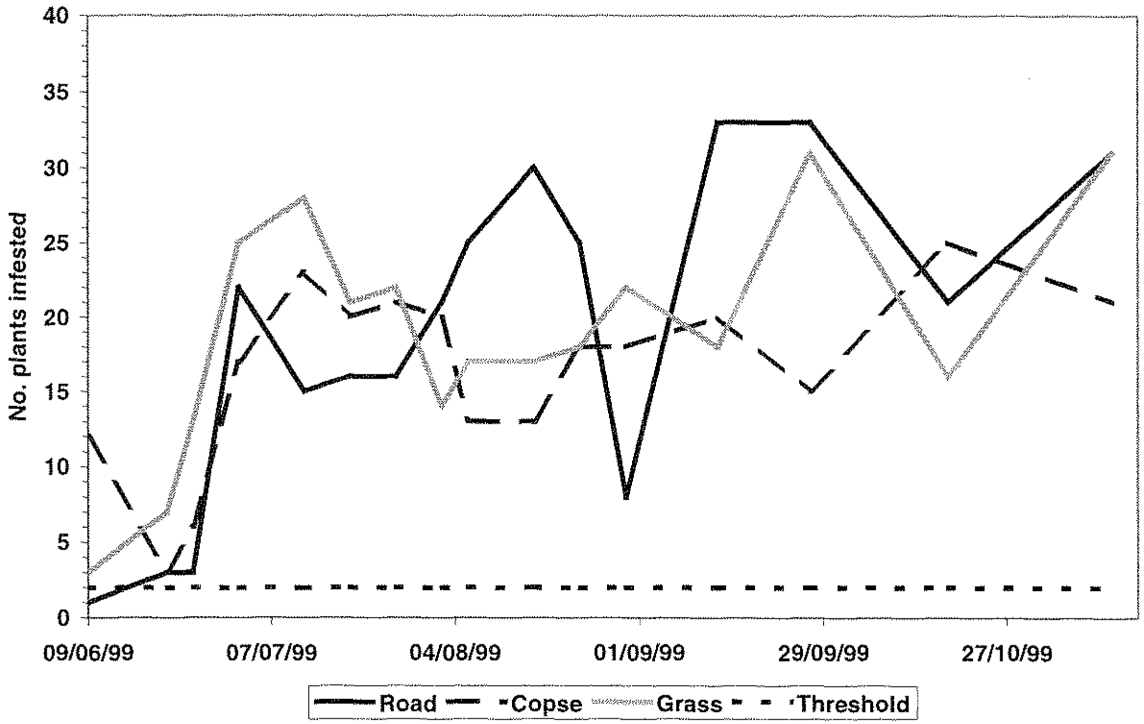


Figure 8. The numbers of Brussels sprout plants infested with caterpillars in the large plot at HRI Kirton in 1999. Forty plants were sampled on each edge on each occasion.

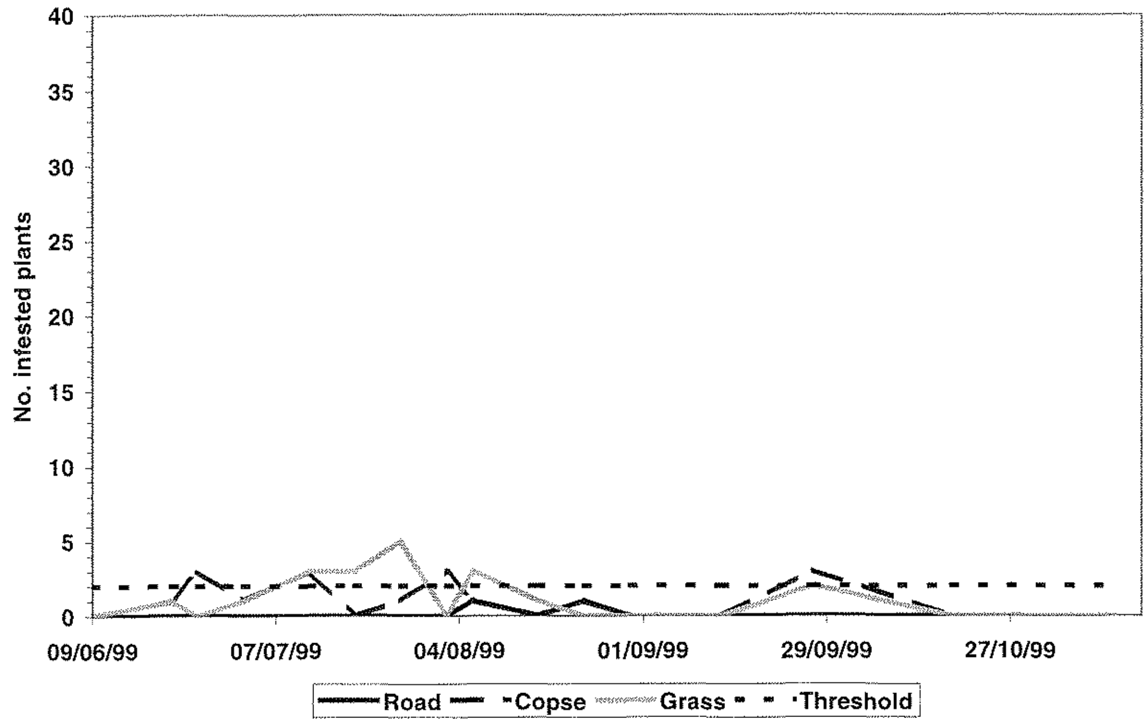
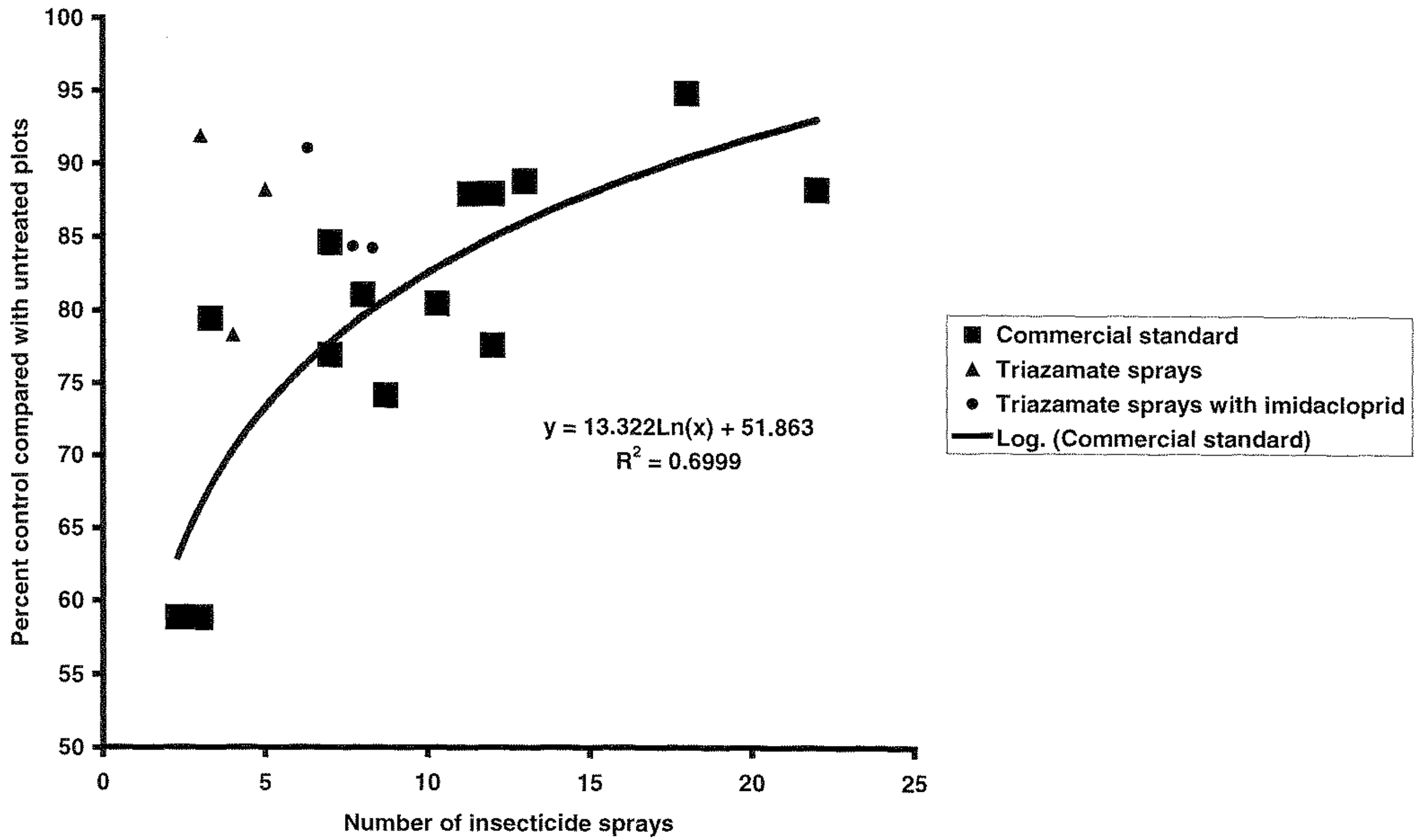


Figure 9. The relationship between the percentage aphid control (compared with untreated plots) and the numbers of OP/carbamate/pyrethroid (commercial standard) sprays applied to experimental plots of Brussels sprouts in 1997-1999 at HRI Kirton. Treatments using triazamate, with or without imidacloprid-treated seed, are included for comparison.

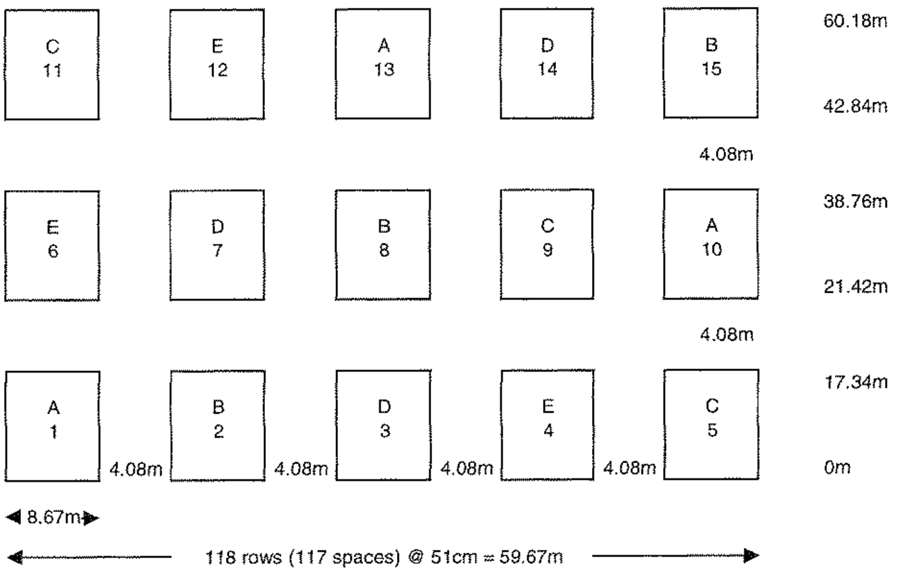


Appendix 1

Plan of small plot trial at HRI Kirton in 1999.

FV194 - 1999

Vicarage 2 - plots
Vicarage 1 - large plot and untreated



Spacing :	51 x 51 cm	Variety :	Diablo
Plot size :	18 x 35 plants 8.67m x 17.34m	Sowing date :	24 March 1999
		Planting date :	
Between plots :	Miss 7 rows (8 spaces), 4.08m		

<u>Vicarage 2</u>

Code	**Treatment**
A	Standard supervised – dimethoate & pirimicarb (Thresholds 5, 5, 5)
B	Imidacloprid seed treatment followed by dimethoate & pirimicarb (Thresholds 5, 5, 5)
C	Imidacloprid seed treatment followed by triazamate (Thresholds 5, 5, 5)
D	Imidacloprid seed treatment followed by triazamate (Thresholds 10, 5, 5)
E	Imidacloprid seed treatment followed by triazamate (Thresholds 20, 5, 5)

<u>Vicarage 1</u>

Large plot	Standard supervised – dimethoate & pirimicarb (Thresholds 5, 5, 5)
Untreated plot	No pesticides to be applied

Use Decis for caterpillars in Vicarage 2 and on large plot

Appendix 2

HRI KIRTON : TRIAL CROP DIARY 1999 - FV194 - SMALL PLOTS

FIELD/SOIL TYPE :	Vicarage 2/Gley soils/mainly fine silts
SOIL ANALYSIS :	pH 7.8 P - 6, K - 3, Mg - 3
PREVIOUS CROPPING :	1998 : Winter wheat 1997 : Autumn & winter brassicas
CULTIVATIONS :	24/08/1998 - Subsoiled 04/11/1998 - Ploughed
FERTILIZER :	24/02/1999 - Sulphate of Potash : 1250 kg/ha 25/02/1999 - Triple Super Phosphate @ 50 kg/ha 12/05/1999 - 120 kg/ha N 05/07/1999 - 150 kg/ha N
SOWN :	24/03/1999 - Diablo sown in 308 trays
PLANT :	20/05/1999 - Planted by hand
HERBICIDES :	05/06/1999 - Dacthal @ 6 kg/ha & Propachlor @ 9 l/ha in 450 l water
INSECTICIDES :	12/07/1999 - Draza @ 5.5 kg/ha 13/09/1999 - Draza @ 5.5 kg/ha See separate sheets for details of treatment application
FUNGICIDES :	26/03/1999 - Aliette & Basilex applied to plants in propagation 04/08/1999 - Folicur @ 0.75 l/ha & Fubol 75 @ 1.5 kg/ha in 600 l 21/09/1999 - Folicur @ 0.75 l/ha in 600 l water 06/10/1999 - Folicur @ 0.75 l/ha in 600 l water
IRRIGATION :	None applied
NOTES :	

Appendix 3

HRI KIRTON : TRIAL CROP DIARY 1999 - FV194 - LARGE PLOT

FIELD/SOIL TYPE :	Vicarage 1/Gley soils/mainly fine silts
SOIL ANALYSIS :	pH 8.0 P - 6, K - 3, Mg - 3
PREVIOUS CROPPING :	1998 : Brussels Sprouts 1997 : Narc. (L), Sp. Cabb, O W Cauli
CULTIVATIONS :	10/12/1998 - Ploughed 26/06/1999 - Trial skerried
FERTILIZER :	24/02/1999 - Sulphate of Potash @ 1250 kg/ha 29/04/1999 - Nitram @ 120 kg/ha N 05/07/1999 - 150 kg/ha N applied
SOWN :	Plants supplied by UNIVEG
PLANT :	19/05/1999 - Started planting var. Diablo
HERBICIDES :	05/06/1999 - Dacthal @ 6 kg/ha & Propachlor @ 9 l/ha in 450 l water 31/08/1999 - Dow Shield @ 0.5 l/ha in 450 l
INSECTICIDES :	12/07/1999 - Draza @ 5.5 kg/ha 13/09/1999 - Draza @ 5.5 kg/ha See separate sheets for details of treatment application
FUNGICIDES :	21/09/1999 - Folicur @ 0.75 l/ha in 600 l water 12/10/1999 - Bravo @ 3 l/ha & Agral @ 150 ml/ha in 1000 l water
IRRIGATION :	None applied
NOTES :	

Appendix 4

Insecticide treatments applied to supervised plots in 1999. Harvest dates are shown also.

Key to insecticides applied

Di = Dimethoate 1.05 l/ha in 600 l + Agral @ 150 ml/ha
P = Pirimicarb 420 g/ha in 600 l + Agral @ 150 ml/ha
T = Triazamate 400 ml/ha in 600 l + Swirl @ 500 ml/ha
De = Deltamethrin 300 ml/ha in 600 l

Treatment A – Standard supervised – dimethoate and pirimicarb
Rep 1 harvested on 19 November, Rep 2 harvested on 23 November, Rep 3 harvested on 25 November.

Aphids						Caterpillars (pyrethroids)					
Rep 1		Rep 2		Rep 3		Rep 1		Rep 2		Rep 3	
19 Jun	P	17 Jun	P	19 Jun	P	23 Jul	De	17 Jul	De	28 Jul	De
11 Jul	P	3 Jul	P	11 Jul	P	23 Aug	De	23 Aug	De		
28 Jul	P	23 Jul	P	28 Jul	P	25 Sep	De				
21 Aug	P	21 Aug	P	21 Aug	P						
10 Sep	P	10 Sep	P	4 Sep	P						
25 Sep	Di	25 Sep	Di	22 Sep	Di						
12 Oct	Di	12 Oct	Di	11 Oct	Di						
9 Nov	Di	9 Nov	Di	28 Oct	Di						
				12 Nov	Di						

Treatment B – Imidacloprid followed by dimethoate and pirimicarb
Rep 1 harvested on 19 November, Rep 2 harvested on 23 November, Rep 3 harvested on 25 November . * Sprayed by mistake.

Aphids						Caterpillars (pyrethroids)					
Rep 1		Rep 2		Rep 3		Rep 1		Rep 2		Rep 3	
26 Jun	P	26 Jun	P	26 Jun	P	17 Jul	De	23 Jul	De	11 Jul	De
13 Jul	P	13 Jul	P	13 Jul	P	2 Aug	De			28 Jul *	De
28 Jul	P	28 Jul	P	28 Jul	P					10 Sep	De
21 Aug	P	21 Aug	P	21 Aug	P						
4 Sep	P	4 Sep	P	4 Sep	P						
22 Sep	Di	22 Sep	Di	22 Sep	Di						
11 Oct	Di	11 Oct	Di	11 Oct	Di						
28 Oct	Di	28 Oct	Di	28 Oct	Di						
12 Nov	Di	12 Nov	Di	12 Nov	Di						

Treatment C – Imidacloprid followed by triazamate (thresholds 5, 5, 5)
Rep 1 harvested on 19 November, Rep 2 harvested on 23 November, Rep 3 harvested on 25 November.

Aphids						Caterpillars (pyrethroids)					
Rep 1		Rep 2		Rep 3		Rep 1		Rep 2		Rep 3	
19 Jun	T	26 Jun	T	26 Jun	T	28 Jul	De	17 Jul	De	17 Jul	De
3 Jul	T	13 Jul	T	13 Jul	T			27 Aug	De		
23 Jul	T	28 Jul	T	2 Aug	T						
21 Aug	T	4 Sep	T	27 Aug	T						
4 Sep	T	21 Sep	T	16 Sep	T						
12 Oct	T	11 Oct	T	4 Oct	T						
		9 Nov	Di	16 Oct	T						
				9 Nov	Di						

Treatment D – Imidacloprid followed by triazamate (thresholds 10, 5, 5)
Rep 1 harvested on 19 November, Rep 2 harvested on 23 November, Rep 3 harvested on 25 November. * Sprayed by mistake.

Aphids						Caterpillars (pyrethroids)					
Rep 1		Rep 2		Rep 3		Rep 1		Rep 2		Rep 3	
26 Jun	T	3 Jul	T	3 Jul	T	6 Aug	De	11 Jul	De	17 Jul	De
13 Jul	T	23 Jul	T	23 Jul	T	4 Oct	De	28 Jul*	De	21 Aug	De
28 Jul	T	9 Aug	T	21 Aug	T						
21 Aug	T	27 Aug	T	4 Sep	T						
16 Sep	T	22 Sep	T	12 Nov	Di						
4 Oct	T										
9 Nov	Di										

Treatment E – Imidacloprid followed by triazamate (thresholds 20, 5, 5)
Rep 1 harvested on 19 November, Rep 2 harvested on 23 November, Rep 3 harvested on 25 November.

Aphids						Caterpillars (pyrethroids)					
Rep 1		Rep 2		Rep 3		Rep 1		Rep 2		Rep 3	
3 Jul	T	3 Jul	T	17 Jul	T	28 Jul	De	28 Jul	De	23 Aug	De
23 Jul	T	28 Jul	T	21 Aug	T						
21 Aug	T	21 Aug	T	10 Sep	T						
4 Sep	T	16 Sep	T	13 Oct	T						
25 Sep	T	4 Oct	T								
		16 Oct	T								
		9 Nov	Di								

Large plot – STANDARD SUPERVISED TREATMENT
Harvested 30 November and 1 December.

Aphids			Caterpillars (pyrethroids)		
Supervised			Supervised		
17 Jun	P		26 Jun	De	
3 Jul	P		13 Jul	De	
23 Jul	P		2 Aug	De	
9 Aug	P		4 Oct	De	
28 Aug	P				
13 Sep	P				
4 Oct	Di				
28 Oct	Di				
12 Nov	Di				