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Evaluation of insecticides for control of apple leaf midge 2001 and 2002

Undertaken for APRC (Project SP129)

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Authentication

I declare this work was done under my supervision according to the procedures described herein and that this report is a true and accurate record of the results obtained.

..... J V Cross
Signature

Date 14 Jan 2003

HRI- East Malling is an officially recognised efficacy testing organisation (ORETO 043)

Evaluation of insecticides for control of apple leaf midge 2001 and 2002

Summary

Three replicated orchard experiments in 2001-2002 evaluated single foliar sprays of insecticides for control of apple leaf midge. In each experiment 6 different products were evaluated, including a Dursban 4 (chlorpyrifos) standard. Two timings of spray application were compared: 1) against eggs before egg hatch commenced 2) against newly hatched larvae in leaf galls. Sprays were applied at the full recommended dose in a spray volume of 500 l ha^{-1}.

A further experiment evaluated a series of four high volume soil drenches of Dursban 4 (chlorpyrifos) in spring against the emergence of first generation adults. Drenches were applied to the weed free strip under the tree at 7-14 day intervals from the start of emergence.

- Aztec (triazamate), Calypso (thiacloprid), Derris (rotenone), Dimilin flo (diflubenzuron), NAF 85 (spinosad) and Runner (UK 859, methoxyfenozide) were ineffective. They did not significantly reduce numbers of eggs laid in shoots or numbers of leaf galls by c. 7 or c. 14 days after treatment.
- The synthetic pyrethroids Decis (deltamethrin), Hallmark (lambda-cyhalothrin), Meothrin (fenpropathrin), Talstar (bifenthrin) and Toppel 10 (cypermethrin) all reduced numbers of eggs laid in shoot tips subsequent to treatment and reduced numbers of leaf galls. Decis, Meothrin, Hallmark, Talstar and Toppel 10 reduced egg numbers by 38-75, 49-91, 55-87, 65-92, 43-68% respectively and numbers of leaf galls by 28-62, 31-70, 34-59, 48-60, 28-58% respectively.
- Hallmark is not approved for use on apple in the UK. The results suggest that, of the approved insecticides, Meothrin and Talstar are the most effective for control of leaf midge. However, these two synthetic pyrethroids are considerably more costly than Decis or Toppel 10.
- Synthetic pyrethroids were thus partially effective and are the only option available to growers to control apple leaf midge. The results suggest that they work by preventing oviposition after treatment either by killing adults or by deterring adults from oviposition. However, this effect is short lived either because more adults emerge after treatment or because new growth is unprotected by insecticide deposit. They may also have some effect on larvae in galls.
- The results suggest that a series of sprays of a synthetic pyrethroid at short intervals (< 7 days) would be necessary to achieve good control of a particular generation of the midge. This approach is not recommended in established apple orchards (see below). Growers would also need to be trained to recognise leaf midge eggs to optimise spray timing.
- Synthetic pyrethroid insecticides are harmful to the orchard predatory mite *Typhlodromus pyri* and would disrupt Integrated Mite Management, probably causing outbreaks of fruit tree red spider mite and apple rust mite. They are also very harmful to adults of the parasitic wasp *Platygaster demades* and to anthocorid predatory bugs, important natural enemies of apple leaf midge. The wasp lays its eggs in the eggs of the leaf midge. Spraying pyrethroid insecticides,

whilst providing some short term chemical control of the midge, may make the pest problem worse in the long term by destroying its key natural enemies. For this reason, synthetic pyrethroids should only be used to control leaf midge in the nursery or possibly during the first year or two of establishment of young orchards.

- Foliar sprays of Dursban 4 (chlorpyrifos) were ineffective in two experiments but partially effective in one experiment when applied at the start of egg laying. In this experiment egg numbers and larval numbers were reduced by 38-66% and 30-64% respectively.
- The programme of four high volume soil drench treatments with Dursban 4, significantly reduced egg numbers and leaf galling but generally by less than 50%. Timing of applications in relation to midge emergence is difficult, particularly when the emergence period is protracted as occurred in April 2002. The effectiveness of the treatment may also depend on soil moisture conditions. The surface of the soil was comparatively dry and this may have hindered penetration of the drench beyond the surface. The results were not nearly as good as those obtained by John Knight (UAP) (Pers. comm.) in a previous small plot experiment where over 90% control was achieved. It may be that in this previous experiment the midge emergence occurred over a comparatively short period and the single soil application was timed to best advantage. Further work to investigate the efficacy of soil treatments is required.
- High volume soil drenching with chlorpyrifos (Dursban) is likely to have undesirable environmental consequences. It may also adversely affect ground dwelling soil predators and other natural enemy fauna, worsening leaf midge outbreaks in the longer term.

Recommendations

- Chemical control of apple leaf midge with the insecticides available currently or likely to become available to UK fruit growers in the foreseeable future is unlikely to be very successful. Other promising chemicals, particularly those that are selective, should be screened as they become available.
- The synthetic pyrethroids are the most effective products but these only give partial control and are harmful the natural enemies of leaf midge and other pests. They should only be used in the nursery or possibly during the first year or two of establishment of new orchards.
- There is a need to provide training to growers and advisors on the recognition of leaf midge adults and eggs so treatments can be timed more accurately.
- Previous UAP trials and the trial reported here on control by soil drenching with chlorpyrifos (Dursban etc) gave conflicting results. Further work to explore this approach is needed, though is of a lower priority because of the adverse side-affects of such treatments.
- The female apple leaf midge in known to produce a powerful sex pheromone which has not yet been identified. Research to identify this pheromone is of the highest priority. Research into the role of predatory ground beetles as natural enemies of leaf midge would also be useful. There may also be some mileage in investigating soil mulches to prevent adult emergence.

Introduction

Apple leaf midge (*Dasineura mali* (Kieffer)) is a widespread and abundant but usually minor pest of apple (Barnes, 1948). The pest attacks young leaves, mainly in growing points, but can also attack rosette leaves. Larvae cause the edges of leaves to roll tightly round themselves to form characteristic leaf galls (Figure 1a). Heavy infestations cause some shortening of the extension growth and sometimes premature leaf fall (Todd, 1956). This is usually of little consequence in established orchards. Occasionally, very severe attacks occur with in excess of 90% of leaves severely affected (Federov, 1962; Carl, 1980; Trapman, 1988), each leaf with large numbers of larvae. Bramley is notably susceptible. Photosynthetic leaf area is greatly reduced, sometimes by over 50%, and this adversely affects fruit size and fruit bud formation. Yield losses of up to 10% have been demonstrated (Kolbe, 1982). The pest is more important on nursery stocks and newly planted trees (Antonin & Baggiolini, 1972; Anon., 1983) and stunting can be severe, the degree of susceptibility being determined by the softness and quantity of terminal growth present.

Apple leaf midge has 3-4 generations per year in the UK, the first around blossom time. Eggs are brown and cigar shaped and are laid amongst hairs in the very tiniest leaves in the growing points (Figure 1b and c). They can just be seen with the naked eye but use of a hand lens is desirable. They hatch after 3-5 days and the larvae (Figure d) feed on the upper epidermis of the leaf causing the margins to roll tightly in characteristic leaf roll galls (Figure 1a). Larval development takes 2-3 weeks. The larvae drop to the ground to pupate in silken cocoons in the soil emerging as adults about 2 weeks later. More details on the life history of the pest are given by Todd (1959).

None of the insecticides approved for use on apple is recommended by the manufacturer for control of apple leaf midge and there is currently no satisfactory control for this pest. The pest appears to be resistant to chlorpyrifos (Dursban etc). Synthetic pyrethroids (bifenthrin (Talstar), cypermethrin (various products), deltamethrin (Decis), fenpropathrin (Meothrin) may be more effective and fenpropathrin (Meothrin) is used for control of the pest in nurseries and on young trees. However, the use of pyrethroids should be avoided as they are harmful to the predatory mite *Typhlodromus pyri* and to the parasitic wasp *Platygaster demades,* the key natural enemy of this pest (see below). Pyrethroids therefore, may do more harm than good in this situation.

The parasitic wasp *Platygaster demades* (Figure 1e) is the key natural enemy of apple leaf midge and will reduce populations to low, tolerable levels if allowed to establish and thrive (Cross *et al.,* 1999; Cross & Jay, 2000). The parasite occurs naturally in the UK but is often absent, or present at only very low levels, in commercial orchards as it is sensitive to broad-spectrum insecticides. It can be introduced on infested leaves from other orchards if necessary (Cross & Jay, 2000). The parasite lays its eggs in the eggs and young larvae of the apple leaf midge. The adult parasite is synchronised with its host but is vulnerable to insecticides including to residues on leaf surfaces. The other life stages of the parasite are probably less susceptible to insecticides as they occur within the host insect. To foster the parasite, the use of broad-spectrum insecticides should be avoided during the egg-laying period of the leaf midge.

Effective insecticides are needed for control of apple leaf midge in the UK. Ideally, insecticides need to be selective with minimal effects on natural enemies, especially the orchard predatory mite *Typhlodromus pyri* and the parasitic wasp *Platygaster*

demades. There is little information on the comparative efficacy against the leaf midge of the existing insecticides that are approved for use on apple, nor information on how efficacy is affected by spray timing in relation to the phenology of the pest.

The results of a series of four experiments, funded by the APRC and conducted by HRI-East Malling in 2001 and 2002, to screen existing insecticides for their efficacy of control of apple leaf midge and to identify the best time of application are reported here. Three of the experiments evaluated a wide range of insecticides as foliar sprays. In these experiments two spray timings were compared: 1) against eggs only (i.e. at the start of an attack by a generation of leaf midge); 2) against eggs and young larvae in newly formed galls (i.e. when the first signs of damage form an attack by a generation of leaf midge were apparent). In the fourth experiment the effect of a series of high volume soil drenches of chlorpyrifos (Dursban 4), covering the emergence period of first generation adults in spring, was evaluated. A previous small plot trial by John Knight (UAP) (pers. comm.) had given very good results; leaf midge attack was reduced by over 90%.

Methods and materials

Sites

The three foliar application experiments were done in a mature apple orchard (Coalpitts) at Broadwater farm, West Malling, Kent by kind permission of the manager, Mr Chris Patt, using single tree plots. The orchard was planted in 1977 with the variety Bramley's seedling with Grenadier pollinators. The rootstock was MM106 and the trees fully established. The row spacing was 6.71 m (22') and the tree spacing in the row 5.49 m (18'). The experiments were done using the Grenadier pollinators only, which occurred as every second tree in every fourth row. The orchard was chosen because it had a history of heavy infestation by apple leaf midge. The Grenadier pollinators were used because they had very numerous vigorous shoots growing from the main branch framework which were highly susceptible to leaf midge attack (Figure 1f). Furthermore, the fruit from this pollinator variety was of low value and the trees were well separated from each other by larger Bramley trees which provided excellent guarding from interplot contamination by spray drift.

The soil drenching experiment was done in a similar MM106 Bramley orchard (New Barns, central section) nearby on the same farm, the whole of the orchard (2.6 ha) being divided into 20 large plots (see *Experiment designs* below).

Treatments

In each of the three foliar application experiments, single foliar sprays of six different insecticides were evaluated each at two different timings of application (Tables 1-3). Each insecticide was applied either against eggs before egg hatch commenced (timing A) versus (in separate plots) against eggs and newly hatched larvae in leaf galls (timing B). In the third foliar application experiment in June 2002, an additional spray timing (timing C) was applied 9 days after timing B. At timing C eggs, young and mature larvae were present in newly formed and older leaf galls respectively. The timings for application of the sprays were determined by twice weekly monitoring of the occurrence of eggs and larval damage in the shoots. In each experiment, chlorpyrifos (Dursban 4) was included as a standard together with an untreated control treatment which was double replicated (triple replicated in the third foliar application experiment where three timings were compared). This provided a separate control plot for each spray timing in each block.

a)

b)

c)

Figure 1. a) Characteristic leaf roll galls caused by apple leaf midge larvae b) female midge ovipositing in growing point c) eggs in growing point


d)


e)


f)

Figure 1 continued. d) larvae from within leaf roll gall e) the parasitic wasp *Platygaster demades* f) single Grenadier pollinator apple trees with vigorous shoot growth used for each plot in the experiment.

In the soil drenching experiment in spring 2002, a soil drenching treatment comprising four applications of chlorpyrifos (Dursban 4) to the soil in the weed free strip under the tree in April and early May, was compared with an untreated control (Table 4). Thus there were only two treatments in this experiment.

Spray application

In each of the three foliar application experiments, sprays were applied with a Cooper Pegler Hurricane Minor air-assisted knapsack sprayer (high pressure setting, no. 3 (yellow) flow restrictor). The sprayer had a single air shear nozzle to atomise the spray. Sprays were applied at a spray volume of 500 l ha^{-1}. The spray liquid flow rate from the sprayer (1.08 l min^{-1}) was measured before application so that the duration of spraying of each tree (102 s) to attain the required volume rate could be determined. The actual spray volume applied for each treatment was determined by measuring the volume of sprayate remaining in the spray tank after treatment. The accuracy of spray application for the application times was within 20% (Table 5).

In the soil drenching experiment, the drenches were applied by the grower using a horizontal jet from the hand lance ports of a Berthoud sprayer, with the nozzles removed, at a spray volume of 1000 l/ha. A preliminary test showed that this method gave good cover of the soil surface. The drench was applied to the weed free strip (herbicide strip) under the trees only.

Experiment designs

Randomised complete block experimental designs with four replicates were used for the three foliar spray application experiments, different randomisations being used for each. Untreated controls were double replicated in the first and the second experiment and triple replicated in the third providing a separate control plot for each spray timing. Plots were single trees guarded on each side in the row by two unsprayed Bramley trees. The plots in each block were arranged end to end in a row, four separate rows containing plots each separated by three guard Bramley rows thus being used for each experiment.

A randomised complete block design with ten replicates was used for the soil drenching experiment. The plots were arranged side by side. Each plot was five rows wide and 19 trees long, the entire length of the orchard, except the first and the last plots which were three rows wide. Assessments were done in the central row of the plot only.

Assessments

Dates when assessments were done and the intervals between treatments and assessments are given in Table 6. In the first foliar application experiment, the 'first assessment' was done 5 days after the first spray application for each spray timing. The number of ovipositing females in a sample of 25 shoots per plot was recorded. The number of leaves in each shoot which had leaf galls was counted and the number of eggs in each shoot were scored into categories as follows: 1 = no eggs present, 2= 1-50 eggs present, 3= 51-200 eggs present, 4 = > 200 eggs present. A 'second assessment' was done 13-14 days after treatment using the same methods as in the first assessment.

In the other foliar application experiments, similar assessments were done but a sample of 30 shoots was examined per plot, 15 from the centre and 15 from the periphery of the tree. Also, the scoring categories for egg numbers were narrowed as follows: 0 = no eggs present, 1 = 1-10 eggs present, 2= 11-40 eggs present, 3 = 41-80

eggs present, 4 = > 80 eggs present. The 'first assessment' was done 5-8 days after the first spray application for each timing and the 'second assessment' was done 13-14 days after treatment.

Assessments were done in the soil drenching experiment on 3-8 May, 24 May and 5 June 2002 using the same methods as the second and third foliar application experiments.

In the first foliar application experiment, additional assessments were done as follows: On 5 July 2001, approximately 24 hours after the first spray application, possible oviposition deterrent effects of the treatments were assessed by counting the number of ovipositing females in the growing points of a random sample of 25 shoots per plot. The assessment was made visually *in situ* so that ovipositing females, which are readily visible to the naked eye, were not disturbed.

On 18 July 2001, 14 days after the application of treatments with spray timing A and 6 days after the application of treatments with spray timing B, the number of live larvae present in galls was estimated. A sample of 20 galls per plot, two from each of 10 shoots, was examined. Ten shoots were sampled at random per plot and placed in labelled plastic bags. In the laboratory, two galls per shoot were cut open with a scalpel and the number of larvae present counted under a binocular microscope. On 26 July 2001, 14 days after the applications at time B, the numbers of live larvae were assessed on the plots that had received sprays at time B and the untreated controls using the same methods. These assessments were not done in the second or third foliar application experiments.

Statistical analysis

For the first foliar application experiment, the number of eggs present per shoot was estimated from the scores as follows:

Estimated number eggs per shoot =.[(25 x no. shoots with score 2)
+ (100 x no. shoots with score 3)
.+.(200 x no shoots with score 4)]/25

For all other experiments where the revised scoring system was used, the number of eggs present per 30 shoots was estimated from the scores as follows:

Estimated number eggs per 30 shoots =.[(5 x no. shoots with score 1)
+ (25 x no. shoots with score 2)
+ (60 x no. shoots with score 3)
.+.(100 x no shoots with score 4)]

Analysis of variance was done on the data, with appropriate square root transformation where necessary.

Table 1. Treatments in the first foliar application experiment in July 2001.

Product	Active ingredient and formulation	Timing†	Dose product (l /ha)	Conc. (ml/l)
Dursban 4	chlorpyrifos 480 g/l EC	A	2.0	4.0
Toppel 10	cypermethrin 100 g/l EC	A	0.28	0.56
Derris	rotenone 50 g/l EC	A	2.5	5.0
XL-nicotine	nicotine 950 g/l LI	A	0.665	1.33
Aztec	triazamate 140 g/l EW	A	0.5	1.0
Calypso	thiacloprid 480 g/l SC	A	0.375	0.75
Dursban 4	chlorpyrifos 480 g/l EC	B	2	4
Toppel 10	cypermethrin 100 g/l EC	B	0.28	0.56
Derris	rotenone 50 g/l EC	B	2.5	5.0
XL-nicotine	nicotine 950 g/l LI	B	0.665	1.33
Aztec	triazamate 140 g/l EW	B	0.5	1
Calypso	thiacloprid 480 g/l SC	B	0.375	0.75
Untreated	untreated	-	-	-

† Timing A: Against eggs only on 4 July 2001
Timing B: Against eggs and young larvae in galls on 12 July 2001

Table 2. Treatments in the second foliar application experiment in April/May 2002.

Product	Active ingredient and formulation	Timing†	Dose product (l /ha)	Conc. (ml/l)
Talstar	bifenthrin 100 g/l EC	A	0.6	1.2
Hallmark	lambda-cyhalothrin 100 g/l CS	A	0.090	0.18
Meothrin	fenproprathin 100 g/l EC	A	0.5	1.0
Decis	deltamethrin 25 g/l EC	A	0.25	0.5
Dursban 4	chlorpyrifos 480 g/l EC	A	2.0	4.0
Toppel 10	cypermethrin 100 g/l EC	A	0.28	0.56
Talstar	bifenthrin 100 g/l EC	B	0.6	1.2
Hallmark	lambda-cyhalothrin 100 g/l CS	B	0.090	0.18
Meothrin	fenproprathin 100 g/l EC	B	0.5	1.0
Decis	deltamethrin 25 g/l EC	B	0.25	0.5
Dursban 4	chlorpyrifos 480 g/l EC	B	2.0	4.0
Toppel 10	cypermethrin 100 g/l EC	B	0.28	0.56
Untreated	-	-	-	-

† Timing A: Against eggs only on 25 April 2002
Timing B: Against eggs and young larvae in galls on 3 May 2002

Table 3. Treatments in the third foliar application experiment in June/July 2002.

Product	Active ingredient and formulation	Timing†	Dose product (l /ha)	Conc. (ml/l)
Calypso	thiacloprid 480 g/l SC	A	0.375	0.75
Dimilin flo	diflubenzuron 480 g/l SC	A	0.3	0.6
Runner UK 859	methoxyfenozide	A	0.6	1.2
NAF-85	spinosad	A	0.45	0.9
Dursban 4	chlorpyrifos 480 g/l EC	A	2.0	4.0
Meothrin	fenproprathin 100 g/l EC	A	0.5	1.0
Untreated		-	-	-
Calypso	thiacloprid 480 g/l SC	B	0.375	0.75
Dimilin flo	diflubenzuron 480 g/l SC	B	0.3	0.6
Runner UK 859	methoxyfenozide	B	0.6	1.2
NAF-85	spinosad	B	0.45	0.9
Dursban 4	chlorpyrifos 480 g/l EC	B	2.0	4.0
Meothrin	fenproprathin 100 g/l EC	B	0.5	1.0
Untreated		-	-	-
Calypso	thiacloprid 480 g/l SC	C	0.375	0.75
Dimilin flo	diflubenzuron 480 g/l SC	C	0.3	0.6
Runner UK 859	methoxyfenozide	C	0.6	1.2
NAF-85	spinosad	C	0.45	0.9
Dursban 4	chlorpyrifos 480 g/l EC	C	2.0	4.0
Meothrin	fenproprathin 100 g/l EC	C	0.5	1.0
Untreated		-	-	-

† Timing A: Against eggs only on 19 June 2002
Timing B: Against eggs and young larvae in galls on 25 June 2002
Timing C: Against eggs and larvae in galls on 4 July 2002

Table 4. Treatments in the soil drenching experiment in spring 2002.

Product	Active ingredient and formulation	Dose product (l /ha)	Conc. (ml/l)
Dursban 4†	Chlorpyrifos 480 g/l EC	2.0	2.0
Untreated	-	-	-

†Drenches applied in 1000 l/ha on 4, 19, 25 April and 2 May 2002

Table 5. Accuracy of spray applications.

	Accuracy of application (% applied/required)		
	Timing A	Timing B	Timing C
First foliar application experiment			-
Dursban 4	107	113	-
Toppel 10	116	105	-
Derris	107	95	-
XL-nicotine	105	115	-
Aztec	97	114	-
Calypso	100	94	-
Second foliar application experiment			
Talstar	92	99	-
Hallmark	113	96	-
Meothrin	104	101	-
Decis	93	91	-
Dursban 4	95	93	-
Toppel 10	115	93	-
Third foliar application experiment			
Calypso	100	105	105
Dimilin flo	unknown (spillage)	95	93
Runner UK 859	90	95	103
NAF-85	91	91	99
Dursban 4	100	108	101
Meothrin	94	105	92

Table 6. Dates of treatments and assessments

Experiment	Spray timing	Spray date	First assessment		Second assessment		Third assessment	
			Date	dat	Date	dat	Date	dat
First Foliar (2001)	A	4 Jul	9 Jul	5	17 Jul	13		
	B	12 Jul	17 Jul	5	26 Jul	14		
Second Foliar (2002)	A	25 April	3 May	8	9 May	14		
	B	3 May	10 May	7	16 May	13		
Third Foliar (2002)	A	19 Jun	25 Jun	6	2 Jul	13		
	B	25 Jun	2 Jul	7	9 Jul	14		
	C	4 Jul	9 Jul	5	17 Jul	13		
Soil drench (2002)	4, 19, 25 April and 2 May		3-8 May	1-6	24 May	22	5 Jun	34

dat = days after treatment

Results

First foliar application experiment in July 2001 (Table 7)
Although casual observation suggested that the number of ovipositing females was greatly reduced immediately after spray application, oviposition recommenced rapidly on all plots and there were no significant differences between treatments in the mean numbers of ovipositing females per shoot 24 hours later. There were no obvious treatment differences when further assessments were made 5 days after the time A and time B spray applications, though numbers were too small and variable for meaningful statistical analysis.

Statistical analysis of square root transformed data showed that there were statistically significant treatment effects on the estimated numbers of eggs present per shoot both 5 and 13-14 dat (days after treatment) for the time A treatment applications and 5 dat for the time B treatment applications. The transformed means for some of the treatments were significantly ($P<0.05$) greater than the mean for the control, notably for Dursban in all three cases, 13-14 dat timing A for Toppel and 5 dat for timing A & B for Calypso.

Statistical analysis of the square root transformed numbers of larvae per gall showed statistically significant treatment effects at the 13-14 dat assessments for both spray timings A & B but not for the 5 dat assessment for the timing B treatment applications . At the 13-14 dat assessment, all the time A spray treatments reduced numbers of larvae per gall significantly ($P<0.05$) compared to the untreated control but at the B spray timing, only the Dursban significantly reduced numbers of larvae per shoot. Reductions in numbers were modest and did not exceed 60%.

None of the treatments significantly affected the numbers of leaf galls per shoot at either the 5 dat or 13-14 dat assessments for either of the spray timings.

Second foliar application experiment in April/May 2002 (Table 8)
Numbers of ovipositing females per 30 shoots present 7-9 dat and 14 dat were very small and erratic and no differences between treatments were apparent either for the first spray application against eggs (timing A) or for the second applications against eggs and young larvae (timing B) .

All the pyrethroid insecticide treatments when sprayed either timing A or B reduced the estimated numbers of eggs per 30 shoots compared to the untreated control significantly ($P<0.05$). Estimated numbers of eggs were significantly less than the control in all cases except for Toppel and Decis at timing B assessed 14 dat where mean values were less than the control but not significantly less at the $p \leq 0.05$ level (reductions were significant 7-9 dat). The pyrethroid treatments reduced numbers of eggs by 38-92%. Talstar was the best or amongst the best treatment in all four data sets for numbers of eggs. Although the mean values for Dursban were consistently lower than the control in all cases, differences were small and not significant statistically.

Treatment effects were not statistically significant for the number of leaf galls per 30 shoots in any of the untransformed data nor in the square root transformed data for 7-9 dat for either the A or B timings of application. However, statistically significant treatment affects were apparent in the square root transformed data for both spray timings at the 14 dat assessment. All the spray treatments reduced the mean square root numbers at both spray timings. Again, Talstar had the lowest mean value in both data sets.

Third foliar spray application experiment in June/July 2002 (Table 9)
F probability values from the analyses of variance showed that treatment effects were all highly statistically significant for timing A spray applications against eggs. However, only the Meothrin treatment reduced estimated numbers of eggs or leaf galls per 30 shoots significantly compared to the untreated control. Assessments of trees treated with Meothrin showed egg numbers were reduced by 84% 6-8 dat and by 61% 14 dat: gall numbers were reduced by 70% 6-8 dat and by 59% 14 dat. None of the other treatments were effective.

Treatment effects were highly statistically significant for the egg counts for timing B spray applications but for the gall counts only the square root transformed data for the 14 dat assessment showed significant differences. Again, Meothrin was the only effective treatment; it reduced estimated egg numbers by 91% 6-8 dat and by 54% 14 dat and gall numbers by 43% 14 dat.

Results for the timing C spray applications were similar to those from timing B, though the data contained irregularities.

Soil drenching experiment in spring 2002 (Table 10)
At the first assessment on 3-8 May, 2-6 days after the last drench treatment had been applied, small numbers of ovipositing adult females were present in the growing points. These females were mainly found in the centre of the tree, both on the Dursban 4 drenched and the untreated plots. The numbers recorded were small and erratic and there was no obvious difference between treatments. However, the numbers of eggs present in the growing points on this assessment date were significantly smaller on the drenched plots than the untreated. Numbers of eggs were reduced by 65%. However, there was no significant difference in the numbers of galls, though the mean value for the Dursban drench treatment was less than the value for the untreated control.

Similar trends in the data are apparent for the second assessment on 24 May, 22 days after the last drench application. The drench treatment significantly reduced both numbers of eggs and leaf galls by 36% and 24% respectively compared to the untreated control.

Differences between treatments in the number of galls were still apparent when the third assessment was done 34 days after treatment. The Dursban drenched plots had 35% less leaf galls than the untreated controls.

Table 7. First foliar application experiment in July 2001: Mean (and mean square root (√) transformed) numbers leaf midge adults, eggs, larvae and leaf galls per shoot

Treatment	Mean no. of ovipositing females / 25 shoots		Estimated no. eggs / shoot		Mean √ no. eggs / shoot		Mean no. of larvae /leaf gall		Mean √ no. of larvae /leaf gall		Mean no. of leaf galls / shoot		Mean √ no. of leaf galls / shoot	
Days after treatment (dat)	5 dat	13-14 dat	5 dat	13-14 dat	5 dat	13-14 dat	5 dat	13-14 dat	5 dat	13-14 dat	5 dat	13-14 dat	5 dat	13-14 dat
Dursban 4 A	2.3	1.3	72	52	8.26	7.09	-	20.5	-	4.52	4.52	5.52	2.12	2.35
Toppel 10 A	2.8	1.5	42	56	6.47	7.40	-	17.2	-	4.07	4.54	4.71	2.12	2.16
Derris A	1.0	1.8	45	21	6.44	4.51	-	28.7	-	5.34	4.86	5.58	2.20	2.36
XL-All nicotine 95% A	2.0	0.5	57	28	7.46	5.28	-	30.2	-	5.36	4.22	5.16	2.05	2.27
Aztec A	3.0	1.5	48	18	6.89	4.23	-	22.3	-	4.65	4.85	5.55	2.20	2.35
Calypso A	2.3	1.3	75	34	8.59	5.56	-	29.2	-	5.31	4.54	5.52	2.13	2.35
Untreated	3.5	1.0	38	21	6.10	4.40	-	45.2	-	6.72	4.78	5.55	2.18	2.36
SED (18 df)					0.742	0.866			-	0.603			0.091	0.090
F prob					0.022	0.006			-	0.010			0.639	0.296
Dursban 4 B	1.3	2.0	37	25	5.92	4.71	19.5	19.6	4.30	4.42	5.30	6.59	2.30	2.56
Toppel 10 B	1.3	2.8	9	37	2.79	6.01	29.1	28.4	5.38	5.32	5.56	6.37	2.36	2.52
Derris B	2.0	1.0	25	14	4.56	3.69	33.2	30.6	5.74	5.50	5.48	6.47	2.34	2.54
XL-All nicotine 95% B	1.3	3.0	22	14	4.61	3.74	30.0	27.3	5.44	5.22	5.25	6.64	2.29	2.58
Aztec B	1.0	0.8	23	21	4.67	4.16	33.1	24.3	5.72	4.89	5.73	6.88	2.39	2.62
Calypso B	3.3	0.5	39	13	6.21	3.51	27.9	30.7	5.14	5.54	5.19	6.71	2.28	2.59
Untreated	0.8	1.8	15	20	3.84	4.35	34.4	29.9	5.73	5.46	5.58	6.58	2.36	2.57
SED (18 df)					0.697	0.829			0.550	0.334			0.058	0.098
F prob					0.002	0.099			0.167	0.035			0.405	0.975

Table 8. Second foliar application experiment in April/May 2002: Mean (and mean square root (√) transformed) numbers leaf midge adults, eggs and leaf galls per 30 shoots.

Treatment/timing	Mean no. of ovipositing females / 30 shoots		Estimated no. of eggs / 30 shoots				No. of leaf galls / 30 shoots			
			Mean		Mean √		Mean		Mean √	
	7-9 dat	14 dat	7-9 dat	14 dat	7-9 dat	14 dat	7-9 dat	14 dat	7-9 dat	14 dat
Talstar A	0	0	38	31	5.55	2.67	4.6	7.0	1.37	1.87
Hallmark A	0	0	41	19	6.21	2.98	4.1	7.4	1.42	2.04
Meothrin A	0	0.3	42	66	5.36	6.30	6.8	11.3	1.96	2.71
Decis A	0	0	28	44	4.83	5.54	7.3	6.6	1.82	2.20
Toppel 10 A	0.1	0.1	39	46	5.13	5.69	5.6	7.3	2.04	2.10
Dursban 4 A	0.4	0.1	69	50	7.72	6.01	6.9	6.3	1.82	2.06
Untreated	0.4	0.1	112	145	9.98	11.46	9.9	17.4	2.36	3.90
SED (18 df)			19.3	35.4	1.385	2.537	1.73	3.62	0.332	0.585
F prob			0.006	0.046	0.017	0.054	0.064	0.062	0.095	0.035
Talstar B	0	0.10	46	18	5.79	3.21	10.1	9.3	2.59	2.32
Hallmark B	0.1	0	59	52	7.08	6.58	19.5	11.8	4.04	3.12
Meothrin B	0	0	67	94	8.05	8.70	11.3	9.3	2.74	2.36
Decis B	0	0.3	81	122	8.20	10.25	13.5	12.9	3.39	3.34
Toppel 10 B	0	0.4	48	128	6.26	10.82	14.0	12.9	3.24	3.30
Dursban 4 B	0.1	0.1	126	198	10.62	13.08	17.0	11.6	3.75	3.29
Untreated B	0	0.4	130	223	10.98	14.07	14.1	17.9	3.35	3.80
SED (18 df)			25.9	NA	1.501	2.010	3.04	3.12	0.538	0.072
F prob			0.020	NA	<0.020	<0.001	0.102	0.140	0.161	0.007

NA = analysis of variance not appropriate; dat = days after treatment

Table 9. Third foliar application experiment in June/July 2002.Mean (and mean square root (√) transformed) numbers leaf midge adults, eggs and leaf galls per 30 shoots.

Treatment/timing	Mean no. ovipositing females / 30 shoots		Estimated no. of eggs / 30 shoots				No. of leaf galls / 30 shoots			
			Mean		Mean √		Mean		Mean √	
Days after treatment	6-8 dat	14 dat	6-8 dat	14 dat	6-8 dat	14 dat	6-8 dat	14 dat	6-8 dat	14 dat
Calypso A	1.1	0.1	500	738	20.99	26.46	5.1	49.1	2.02	6.911
Dimilin flo A	1.3	0.3	497	784	21.48	27.69	12.3	48.9	3.24	6.934
Runner UK 859 A	1.8	0	392	734	18.50	26.85	3.4	35.4	1.29	5.838
NAF 85 A	1.1	0	374	762	18.27	26.91	4.9	49.9	1.62	6.934
Dursban 4 A	2.9	0.4	347	811	17.04	27.87	7.0	36.0	2.15	5.862
Meothrin A	0.5	0	56	276	6.55	15.64	1.9	20.6	0.78	4.343
Untreated A	0.7	0	349	714	17.72	26.50	6.3	50.5	1.97	7.012
SED (18 df)			90.1	95.5	2.132	1.789	2.17	8.61	0.536	0.6825
F prob			0.007	<0.001	<0.001	<0.001	0.014	0.019	0.006	0.008
Calypso B	0	0.3	725	697	26.65	25.90	29.1	72.4	4.95	8.45
Dimilin flo B	0.4	0.6	706	656	26.23	25.31	50.1	78.7	6.97	8.68
Runner UK 859 B	0.1	0.8	686	774	25.63	27.39	44.4	91.6	6.47	9.55
NAF 85 B	0.1	0.4	749	684	27.07	26.07	56.9	96.4	7.47	9.79
Dursban 4 B	0	0.5	577	585	23.93	23.90	34.6	61.7	5.83	7.80
Meothrin B	0	0.1	62	333	7.45	17.32	37.5	51.2	5.98	6.96
Untreated B	0	0.6	689	727	25.58	26.62	41.1	90.1	6.12	9.32
SED (18 df)			115.5	105.4	2.351	2.097	9.77	15.02	0.830	0.879
F prob			<0.001	0.012	<0.001	0.003	0.143	0.063	0.128	0.050

Continued overleaf.....

.....Table 9 continued.

Treatment/timing	Mean no. ovipositing females / 30 shoots		Estimated no. of eggs / 30 shoots Mean		Estimated no. of eggs / 30 shoots Mean √		No. of leaf galls / 30 shoots Mean		No. of leaf galls / 30 shoots Mean √	
Days after treatment (dat)	6-8 dat	14 dat	6-8 dat	14 dat	6-8 dat	14 dat	6-8 dat	14 dat	6-8 dat	14 dat
Calypso C	1.6	0.1	616	272	24.49	16.03	92.7	154.4	9.62	12.41
Dimilin flo C	1.3	0	554	214	22.85	14.15	92.9	148.5	9.62	12.17
Runner UK 859 C	1.8	0.1	519	170	22.11	12.84	91.4	147.8	9.54	12.12
NAF 85 C	0.8	0	589	217	23.85	14.38	90.1	151.6	9.47	12.28
Dursban 4 C	0.4	0.1	293	257	16.79	15.79	87.9	135.8	9.34	11.62
Meothrin C	0.3	0.3	34	371	5.23	18.46	73.6	110.9	8.49	10.47
Untreated C	2.4	0	513	218	22.23	14.48	92.5	164.6	9.58	12.78
SED (18 df)			81.5	46.1	1.705	1.360	8.72	12.44	0.472	0.521
F prob			<0.001	0.011	<0.001	0.018	0.328	0.012	0.245	0.009

Table 10. Soil drenching experiment Spring 2002: Mean (and mean square root (√) transformed) numbers of ovipositing leaf midge adults, eggs and leaf galls.

		Dursban drenched	Untreated control	SED (9 df)	Fprob
First assessment (3-8 May)					
No. ovipositing females/30 shoots		0.30	0.25	NA	NA
No. eggs/30 shoots	n	61.9	175.8	20.00	<0.001
	√n	6.33	12.42	0.995	<0.001
No. galls/30 shoots	n	8.4	9.7	1.55	0.424
	√n	2.19	2.50	0.308	0.335
Second assessment (24 May)					
No. ovipositing females/30 shoots		0.05	0.05	NA	NA
No. eggs/30 shoots	n	60.2	93.5	13.80	0.039
	√n	6.88	9.28	0.948	0.032
No. galls/30 shoots	n	37.6	49.5	4.32	0.022
	√n	5.59	6.71	0.333	0.008
Third assessment (5 June)					
No. shoots out of 50 with no galls	n	16.8	9.6	1.356	<0.001
	√n	4.08	3.05	0.201	<0.001
No. galls/50 shoots	n	107.1	164.9	11.93	<0.001
	√n	10.31	12.79	0.513	<0.001

NA = analysis of variance not appropriate

Discussion

Foliar application experiments

The pyrethroid insecticides were the most effective products when applied as foliar sprays. However, they were only partially effective in commercial terms reducing numbers of galls at best by 70%, but often this reduction was less than 50%. Overall, the data suggests that Hallmark, Meothrin and Talstar are more effective than Decis or Toppel 10, though the relative effectiveness of the pyrethroid insecticides varied between experiments. Reductions in egg numbers were usually greater than reductions in numbers of galls. This suggests that the pyrethroid insecticides reduce egg numbers either by preventing or deterring oviposition or by killing adults or a combination of both. However, the effect of an individual spray application is short lived, either because the growing point where eggs are laid soon grows away from its insecticidal deposit or because more adults emerge shortly after treatment. In order to achieve a high degree of control of apple leaf midge, a series of sprays of a pyrethroid insecticide would be needed at short (perhaps 7 day)or possibly very short (2-3 day), intervals. Experimental work is needed to test this approach which is currently speculative. None of the insecticides appeared to noticeably reduce the numbers of larvae inside galls. This contrasts with the situation in blackcurrants where sprays of pyrethroids to control blackcurrant leaf midge in galls actually kill a high percentage (>97%) of larvae inside galls.

Synthetic pyrethroid insecticides are well known to be very harmful to a wide range of natural enemies in orchards. They are harmful to the orchard predatory mite *Typhlodromus pyri* and are likely to lead to outbreaks of pest mites including the fruit tree red spider mite and the apple rust mite. Meothrin (fenpropathrin) and Talstar (bifenthrin) have good acaricidal properties, which may initially prevent pest mite outbreaks. However, these mites are known to develop strains resistant to pyrethroid insecticides rapidly.

The synthetic pyrethroid insecticides are also harmful to the most important natural enemies of apple leaf midge, the parasitic wasp *Platygaster demades* and anthocorid predatory mites. The parasitic wasp lays its eggs in the eggs of the leaf midge. The adult wasp, the life stage most sensitive to insecticides, is thus present when leaf midge eggs are presentwhich is also when insecticidal control measures against the midge are best applied for control. Therefore, the use of broad spectrum insecticides may control the leaf midge to some extent in the short term, but lead to more severe outbreaks in subsequent generations by eliminating the pests most important natural enemies of the pest. For these reasons, it is almost certainly unwise to use synthetic pyrethroids to control apple leaf midge in established orchards. However, there is a case for using pyrethroids on nursery trees where early shoot growth is important and possibly in newly planted orchards during the first year or two of establishment. However, use of synthetic pyrethroids in these ways would delay the establishment of *Typhlodromus pyri* and Integrated Mite Management until several years after intensive use of pyrethroids had ceased. The acaricidal pyrethroids Talstar and Meothrin, which appear most effective against leaf midge, are much more costly than Toppel or Decis.

Soil drenching experiment

The emergence period of first generation adult apple leaf midge was very protracted in April 2002. The weather during the emergence period was changeable which lead to emergence occurring in stages on warmer days. The last 2 weeks of March and the first 3 weeks of April were very dry and there was no significant rainfall over this period until 25-27 April. The surface of the soil was comparatively dry and this may have hindered penetration of the drench beyond the surface. The drench treatment did significantly reduce the first generation leaf midge attack but only partially. The reduction was not good enough to justify such a treatment in commercial terms. The results were not nearly as good as those obtained by John Knight (UAP) (Pers. comm.) in a previous small plot experiment where over 90% control was achieved. It may be that in this pervious experiment the midge emergence occurred over a comparatively short period and the single soil application was timed to best advantage. Further work to investigate the efficacy of soil treatments is required.

Conclusions

- Aztec (triazamate), Calypso (thiacloprid), Derris (rotenone), Dimilin flo (diflubenzuron), NAF 85 (spinosad) and Runner UK 859 (methoxyfenozide) were ineffective. They did not significantly reduce numbers of eggs laid in shoots or numbers of leaf galls by c. 7 or c. 14 days after treatment.
- The synthetic pyrethroids Decis (deltamethrin), Hallmark (lambda-cyhalothrin), Meothrin (fenpropathrin), Talstar (bifenthrin) and Toppel 10 (cypermethrin) all reduced numbers of eggs laid in shoot tips subsequent to treatment and reduced

numbers of leaf galls. Decis, Meothrin, Hallmark, Talstar and Toppel 10 reduced egg numbers by 38-75, 49-91, 55-87, 65-92, 43-68% respectively and numbers of leaf galls by 28-62, 31-70, 34-59, 48-60, 28-58% respectively.

- Hallmark is not approved for use on apple in the UK. The results suggest that, of the approved insecticides, Meothrin and Talstar are the most effective for control of leaf midge. However, these two synthetic pyrethroids are considerably more costly than Decis or Toppel 10.
- Synthetic pyrethroids were thus partially effective and are the only option available to growers to control apple leaf midge. The results suggest that they work by preventing oviposition after treatment either by killing adults or by deterring adults from oviposition. However, this effect is short lived either because more adults emerge after treatment or because new growth is unprotected by insecticide deposit. They may also have some effect on larvae in galls.
- The results suggest that a series of sprays of a synthetic pyrethroid at short intervals (< 7 days) would be necessary to achieve good control of a particular generation of the midge. This approach is not recommended in established apple orchards (see below). Growers need to be trained to recognise leaf midge eggs to optimise spray timing.
- Synthetic pyrethroid insecticides are harmful to the orchard predatory mite *Typhlodromus pyri* and would disrupt Integrated Mite Management, probably causing outbreaks of fruit tree red spider mite and apple rust mite. They are also very harmful to adults of the parasitic wasp *Platygaster demades* and to anthocorid predatory bugs, important natural enemies of apple leaf midge. The wasp lays its eggs in the eggs of the leaf midge. Spraying pyrethroid insecticides, whilst providing some short term chemical control of the midge, may make the pest problem worse in the longer run by destroying its key natural enemies. For this reason, synthetic pyrethroids should only be used to control leaf midge in the nursery or possibly during the first year or two of establishment of young orchards.
- Foliar sprays of Dursban 4 (chlorpyrifos) were ineffective in two experiments but partially effective in one experiment when applied at the start of egg laying. In this experiment egg numbers and larval numbers were reduced by 38-66% and 30-64% respectively.
- The programme of four high volume soil drench treatments with Dursban 4, significantly reduced egg numbers and leaf galling but generally by less than 50%. Timing of applications in relation to midge emergence is difficult, particularly when the emergence period is protracted, as in 2002 when the experiment was done. The effectiveness of the treatment may also depend on soil moisture conditions.

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Data storage

The GEP file for this work is stored in the GEP archive at HRI East Malling.

File reference: ntsm03/cross/labbook/aprcleafmidge/y2002-03/report/APRCleafmidgereport2002.doc