Project Title:	Timing and efficacy of insecticides for control of mussel scale on apple 2007
HDC Project Number:	TF178
EMR Project No.	32895 (GEP no. ORETO 07/010)
Project Leader:	Jerry Cross
Report:	Final report 2007
Previous reports:	None
Key Workers:	Jerry Cross Michelle Fountain Adrian Harris
Location of Project:	East Malling Research Kent ME19 6BJ Tel: 01732 843833 Fax: 01732 849067
Project consultant:	Don Vaughan
Date Project commenced:	1 April 2007
Expected completion date:	31 March 2008
Date of issue of report:	30 October 2007

Principal Scientists:

J V Cross PhD, MA, MBPR (Hort.), FRES (Study Director, author of report)
M Fountain PhD
A Harris MSc

Statistical advisor

G Arnold BA, MSc, CStat (Biometrician)

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 ....

East Malling Research is an Officially Recognised Efficacy Testing Organisation (Certification No. ORETO 206)

Grower summary

TF178

Timing and efficacy of insecticides for control of mussel scale on apple 2007

Headlines

- The Dutch mussel scale migration model did not predict emergence well.
- The emergence and migration of mussel scale crawlers at a high level can be prolonged, lasting for over 4 weeks.
- Gazelle and Calypso were the best products for control of those tested.
- Two or more sprays may be required to give a high degree of control. Sprays are best applied in the latter part of the migration (after 50% emergence) with an interval between sprays of at least two weeks.

Background and deliverables

Mussel scale has been increasing in importance in commercial apple orchards in the UK in recent years, no doubt due to the demise of tar oil winter wash treatments which were very effective at controlling the pest. Calypso is known to be an effective product but single sprays are often only partially effective. The reason for this is not know. It may possibly be due to difficulty of accurate timing (sprays were considered to be most effective when applied at the peak (mass) emergence of crawlers), that this timing is not optimal or that more than one spray is required. Several products are known to have activity against mussel scale, but their relative efficacy has not been investigated. This work aimed to evaluate the timing and efficacy of insecticide spray treatments.

Summary of the project and main conclusions

A field study was conducted in a mussel scale infested 4 row bed Cox orchard at Wares Farm, Linton in 2007 to evaluate the efficacy of foliar spray treatments for control of the pest. The aims were to determine the effects of timing of an application of thiacloprid (Calypso) in relation to crawler emergence on efficacy of control of mussel scale, to evaluate the comparative efficacy of thiacloprid (Calypso), acetamiprid (Gazelle), flonicamid (Mainman), spirodiclofen (Envidor), chlorpyrifos (Dursban WG) and fenoxycarb (Insegar) for control and to validate the Dutch mussel scale temperature based emergence model.

The emergence and migration of mussel scale crawlers was monitored twice weekly from 17 April to 10 July using bands of double sided sellotape round the trunks of untreated trees. A replicated experiment compared the following treatments, applied as foliar sprays (500 l /ha).

- Single sprays of Calypso at 2%, 40% or 98% emergence on 24 April, 1 or 25 May
- Two sprays of Calypso at 98% emergence then 2 weeks later on 25 May and 7 June respectively
- A single spray of Insegar at 2% emergence on 24 April
- Two sprays of Calypso, Insegar, Envidor, Gazelle, Dursban or Mainman at 40% and 98% emergence on 1 May and 25 May

The main period of emergence and migration of mussel scale crawlers lasted for about a month from 23 April to 24 May 2007, but small numbers of crawlers continued to migrate for a further 6 weeks. The peak of the migration occurred on 3 May 2007. The duration of the migration at a high level was much longer than had previously been understood by UK growers and advisors.

Sticky traps consisting of bands of double sided sellotape round the trunks of untreated, infested trees proved very effective for monitoring crawler emergence and migration. At the peak of the migration, 19 crawlers were captured per cm of sticky band per day. Similar numbers of nymphs were caught in total in bands at the top of the tree as in bands the bottom of the tree (~50 cm above the ground). There was some evidence that the migration was slightly earlier at the top of the tree where peak numbers were recorded on 30 April than on the traps at the bottom of the tree where peak numbers were recorded on 3 May.

Predictions of first, peak and 90% crawler emergence were made based on the temperature sum model developed by Helsen et al. (1996) in the Netherlands. The accumulated sum reached the value of 151 Day Degrees > 8 ˚C which gave a predicted date of first emergence of 11 May 2007. The sum reached the values of 190 and 229 Day Degrees > 8 ˚C for peak and 90% emergence on 16 and 24 May 2007. The actual first emergence, peak and 90% emergence dates were 23 April 3 May and 18 May respectively. Thus the model predictions were too late by 18, 13 and 6 days for the first, peak and 90% emergences, respectively. Thus, the model did not give predictions of acceptable accuracy. The lateness of the predictions may possibly be because temperatures on the bark surface, which is exposed to direct sunshine, are substantially higher than air temperatures recorded by weather stations, where temperature sensors are held in a Stevenson's screen.

There was a clear improvement in mussel scale control with increasing time of application of single sprays of Calypso, the spray at 98 % emergence giving the greatest degree of control reducing in the percentage fruits infested by 88% and the number of scales per fruit by 98%. The treatment comprising a single spray of Insegar at 2% emergence gave at best only minimal control of mussel scale. The treatments comprising two sprays of Calypso both had a smaller percentage of fruits infested than the single spray treatments. Of the 6 different products compared as two sprays at 40% and 98% emergence, the Calypso and Gazelle gave the best and similar results, reducing the percentage fruits infested by 94% on average (99% reduction in numbers of scales per fruit). Two sprays of Insegar gave the poorest results, reducing the percentage fruits infested by 28% (40% reduction in the numbers o scales per fruit). Two sprays of Envidor, Dursban or Mainman gave intermediate results, reducing the percentage infestation by 72% on average (87% reduction in numbers of scales per fruit).

Overall, the results indicate that Gazelle and Calypso are the best products but two or more sprays may be required to give a high degree of control of heavy infestations of the pest. The results suggest that the sprays are best applied in the latter part of the migration (after 50% emergence) with an interval between sprays of at least two weeks.

Financial benefits

Financial losses to the fruit industry due to mussel scale have not been estimated but it is not unusual for 10% of fruits to be downgraded due to the pest in heavily infested orchards. The losses and costs of control are very much greater than the costs of the research.

Action points for growers

- The mussel scale crawler migration lasted much longer (4 weeks) than previously reported and good control is unlikely to be achieved with a single insecticide spray.
- Gazelle and Calypso are the most effective products for control of mussel scale of those tested. To control heavy infestations, two sprays should be applied at an interval of at least 2 weeks in the latter part of the migration period (the first at peak emergence or later).
- Envidor, Dursban and Mainman were only partially effective and Insegar had little effect.

Science Section

Timing and efficacy of insecticides for control of mussel scale on apple 2007

Introduction

Mussel scale is a common pest of apple and sometimes pear in the UK. It has been increasing in importance in many apple orchards in recent years. It also occurs on many other woody host plants. Fruit crop hosts include apple, pear, cherry, plum, bilberry and less frequently on currants and gooseberry. Other hosts include blackthorn, cotoneaster, hawthorn, heather and many others. Populations on hawthorn, heather and other wild plants are believed to be the main sources of infestation of orchards. All the commonly grown apple varieties are susceptible to mussel scale. Adults are 2.0-3.5 mm long, flat and mussel–shaped, grey to yellowish brown in colour. They are found on the bark and fruits of apple trees. The nymphs, known as crawlers in the first instar stage, are oval, pale yellowish brown. Eggs are minute, oval and white and are deposited beneath the scale.

The main damage is caused by the presence of mussel scales on the surface of fruits at harvest. The contamination is superficial but may downgrade the fruit. Very heavy infestations on the bark may debilitate the tree and there maybe some contamination of the foliage with honeydew. At first, the upper surface of the leaves assumes a glistening, sticky appearance but it later becomes unsightly with the growth of sooty mould fungi on the honeydew.

Life cycle: Eggs are laid in the autumn and are deposited by the female under the scale shell before she dies. Eggs hatch in late May or early June and the first stage crawlers, wander over the host plant settling on the bark and sometimes on the developing fruit. Each then moults to a second instar and then a third instar nymph, both stages being sedentary remaining in the same place and protected by the mussel-shaped scale formed from wax and the cast nymphal skin. In late August and September, each female deposits up to 80 eggs beneath the scale then dies. The scale remains attached to the bark and protects the eggs through the winter. Although males appear in some races of mussel scale, only females occur on fruit crops and reproduction is entirely parthenogenetic.

Natural enemies: Scale insect populations are host to a complex of natural enemies.

Parasitic wasps include the minute chalcid *Aphytis mytilaspidis* which is a common external parasite of mussel, oyster and pear scales. The egg of the parasite, usually one per scale, is laid under the waxy scale, close to the body of the insect. The wasp has two generations per year and can feed on the second nymphal stage as well as on the adult female. The greatest extent of parasitism of mussel scale recorded was 26%, but in most cases parasitism is much lower. Several other species of parasitic wasp also attack mussel and other scale insects. Levels of parasitism can be assessed by looking for small circular holes in the old scales from which the adult wasps have emerged. However, natural populations of the parasitic wasps do not constitute a significant or reliable regulatory mechanism. Predatory insects including ladybird adults and larvae, mirid and anthocorid buds, predatory mites often destroy large numbers of scales, particularly the vulnerable young stages.

Monitoring: Fruits at harvest are inspected and the percentage of fruits contaminated by mussel scale recorded. If the level is economically significant (e.g. > 1%), then insecticidal treatment may be justified in the dormant period or after blossom the following year. The bark of apple trees may also be examined in the dormant period for signs of infestation.

Forecasting: Helsen et al. (1996) developed a temperature sum simulation model for the timing of emergence of mussel scale crawlers in the Netherlands, based on lab studies of the timing of emergence from infested shoots held in constant temperature incubators in the laboratory. The model was validated against 14 years of field observation data. It forecast first emergence as occurring at 151 Day Degrees >8 ºC after 1 January, 90% emergence at 229 Day Degrees >8 ºC after 1 January. Mass egg hatch occurs at about 190 Day Degrees. 90% hatch occurs at 230 Day Degrees and is considered to be the optimum timing for application of commonly used pesticides.

Cultural control: There are few obvious cultural control measures from this pest. Isolation from hawthorn and other trees that are wild hosts will reduce the probability of infestation developing. Mussel scale populations tend to be greatest in old orchards where the pest has been allowed to increase without check over a number of seasons. Physical destruction of colonies or their removal may be possible but is unlikely to be economic.

Chemical control: A mass hatch of the eggs of mussel scale often occurs in a short time period of a few days in late May or June. Insecticide sprays need to be targeted against the young crawlers that emerge. Mature larvae are protected by their outer scale and are much less susceptible to insecticides. For this reason, pinpointing the timing of the mass hatch is helpful to time sprays correctly. 90% hatch occurs at 230 Day Degrees and is considered to be the optimum timing for application of commonly used pesticides. Early hatched nymphs may reach the second instar stage by this time but these are still susceptible to the commonly used insecticides.

Fatty acids (Savona) is the only insecticide approved for use on tree fruit crops in the UK recommended specifically by the manufacturer for control of scale insects. However, treatment with fatty acids (Savona) is only likely to be effective if high volume sprays are applied to run-off at the full recommended concentration. Such treatment is very costly. A number of insecticides, approved for the control of other pests on top fruit, have been used for mussel scale control with varying degrees of success by UK apple growers. These include thiacloprid (Calypso), acetamiprid (Gazelle), fenoxycarb (Insegar), chlorpyrifos (Equity etc), and the synthetic pyrethroids cypermethrin (Toppel 10 etc) and deltamethrin (Decis etc). The use of pyrethroid insecticides is usually avoided because they are harmful to the orchard predatory mite *Typhlodromus pyri*. For growing season sprays, medium to high volume spraying is important to obtain good cover.

Objectives

The overall aim is to determine cost effective treatments for control of mussel scale on apple

1. To determine the effects of timing of an application of thiacloprid (Calypso) in relation to crawler emergence (at first, 50%, 90% emergence) on efficacy of control of mussel scale.
2. To evaluate the comparative efficacy of thiacloprid (Calypso), acetamiprid (Gazelle), flonicamid (Mainman), Spirodiclofen (Envidor), chlorpyrifos (Dursban WG) and fenoxycarb (Insegar) for control of the pest.
3. To validate the Dutch mussel scale emergence model in 2007.

Methods and materials

Site

The trial was done in beds 41 and 42 of 4 row bed Cox (M9) orchard at Wares Farm, Linton. (located at NGR TQ 743 496) by kind permission of manager Brian Tompsett. The tree density was 3500 trees per ha. Each bed contained approximately 350 trees.

Figure 1. Typical Cox tree in the 4 row bed Cox orchard used for the experiment, photographed on 21 June 2007.

Treatments

Treatments were 3 different timings of spray application of Calypso at progressive stages through the mussel scale crawler migration, 2 Calypso spray treatments at 98% crawler emergence and 2 weeks later and at 40% and 98% crawler emergence, a pre-migration spray of Insegar and a comparison of two sprays of Insegar, Mainman, Envidor, Gazelle and Dursban WG at 40% and 98% migration as shown in Table 1. Products, their formulation details and rates of application are shown in Table 2.

Table 1. Treatments

Treatment	Product	No. of sprays	Timing of application†	Dates of application
A	Calypso	1	2% emergence	24 April
B	Calypso	1	40% emergence	1 May
C	Calypso	1	98% emergence	25 May
D	Calypso	2	98% emergence ,+ 2 weeks	25 May, 7 June
E	Calypso	2	40% emergence, + 98% emergence	1 May, 25 May
F	Insegar WG	1	2% emergence	24 April
G	Insegar WG	2	40% emergence, + 98% emergence	1 May, 25 May
H	Envidor	2	40% emergence, + 98% emergence	1 May, 25 May
I	Gazelle	2	40% emergence, + 98% emergence	1 May, 25 May
J	Dursban WG	2	40% emergence ,+ 98% emergence	1 May, 25 May
K	Mainman	2	40% emergence, + 98% emergence	1 May, 25 May
L	Untreated	0	-	

† It was intended that the sprays should be applied at 1st, 50% and 90% emergence. The actual % emergences were calculated retrospectively from the cumulative catches of crawlers in sticky bands.

Table 2. Products, their parent agrochemical company, formulation details and dose of application

Product	Parent company	Active substance and formulation	Product dose (/ha)
Calypso	Bayer CropScience	thiacloprid 480 g/l SC	375 ml
Dursban WG	Dow	chlorpyrifos 75% w/w WG	1.2 kg
Envidor	Bayer CropScience	spirodiclofen 240 g/l SC	600 g
Gazelle	Certis	acetamiprid 20% w/w SP	375 g
Insegar WG	Syngenta	fenoxycarb 25% w/w WG	600 g
Mainman	Belchim	flonicamid 50% w/w WG	140 g

Monitoring egg hatch and crawler emergence to time sprays

Twice weekly from 25 April to 6 June, a sample 20 of mature (overwintered) scales on shoots and spurs was collected and the numbers of unhatched and hatched eggs counted under a binocular microscope in the laboratory. This enabled estimates of the proportions of eggs that had hatched to be made. On 17 April, 8 pairs sticky traps were deployed as ring bands round the trunks of 8 heavily infested, untreated trees in the experimental plot, to catch emerging mussel scale crawlers. Each pair of traps was deployed on a separate tree, one of the pair towards the top of the tree at a height of approximately 1.6 m above the ground, the other at the bottom of the tree, approximately 50 cm above the ground. The bands were made from double sided sellotape (Figure 1). They were removed and refreshed twice weekly, the replacement being in the same location. The removed bands were transported to the laboratory where the numbers of mussel scale crawlers on each band were counted. The monitoring in this way was continued until 10 July when the migration of crawlers had effectively ceased. Graphs of emergence and percentage hatching were plotted.

Figure 2. Sticky band trap round trunk of tree to monitor numbers of migrating mussel scale crawlers, which can be seen in large numbers. They are under the double sided Sellotape, between the tape and the bark of the tree.

Temperature sum model

A miniature temperature logger was deployed in a Stevenson's screen in the trial orchard to monitor temperature at ½ hourly intervals so that the daily maximum and minimum air temperature could be determined.

Helsen et al (1996) developed a temperature sum simulation model for the timing of emergence of mussel scale crawlers in the Netherlands, based on lab studies of the timing of emergence from infested shoots held in constant temperature incubators in the laboratory. The model was validated against 14 years of field observation data. It forecast first emergence as occurring at 151 Day Degrees >8 ºC after 1 January, peak (mass) emergence at 190 Day Degrees>8 ºC, 90% emergence at 229 Day Degrees >8 ºC after 1 January.

The dates of first, 50% and 90% and 100% emergence in the trial orchard were estimated. DD sums >8 ºC after the 1 January will be calculated from daily maximum and minimum temperature readings using the triangulation method. The temperature sums at the observed dates of emergence will be compared with the temperature sum predictions of the Dutch model. The accuracy of the predictions will be determined.

Spray application

Sprays were applied at a volume of 500 l/ha with a Birchmier motorised air-assisted knapsack sprayer fitted with a red Micron spray restrictor. The average height tree canopy recorded at time of the first spray application was 1.8 m. The Crop Adjustment Factor (CAF) of the trees was 1.0. Pre-treatment calibration showed that the sprayer delivered spray at a flow rate of 426 ml/minute so each tree was sprayed for a duration of 20 seconds (10 seconds each side) to deliver a required spray volume of 136 ml to each tree. Measurement of the volumes of spray solution remaining in the tank after spraying showed that applied spray volumes for each treatment were generally within less than 10% of the required volume (Table 3).

Table 3. Accuracy of spray applications. Note values are only approximate as tank volumes were only measured to the nearest 100 ml

24 April		1 May		25 May		7 June	
Trt	%	Trt	%	Trt	%	Trt	%
A	104	B	84	C	103	D	101
F	84	E	84	D	103		
		G	100	E	103		
		H	81	G	107		
		I	105	H	106		
		J	105	K	106		
		K	105	J	100		
				I	106		

Met conditions at the time of spraying

Wet and dry bulb temperature, wind speed and direction were recorded before and after spraying. All sprays were applied in dry conditions. Temperatures and relative humidities estimated from the air temperature and depression of the wet bulb temperature are given in Table 4.

Table 4. Air temperature and humidity conditions at the time of spray application

Date (2007)	At beginning of spray applications					At end of spray applications				
	h	Temp (˚C)			Windspeed (km/h)	h	Temp (˚C)			Windspeed (km/h)
		Dry bulb	Wet bulb	RH%			Dry bulb	Wet bulb	RH%	
24 April	09:40	16.5	13		0	10:00	16.5	13		0
1 May	07:20	13.5	10		13	09:50	19.5	13		6
25 May	08:45	19	16		2-4	12:55	24.5	20		2-4
7 June	11:00	17	15		11 gust 13	11:19	17	15		11

Experimental design and layout

A randomised complete block experimental design with 4 replicate plots of each treatment was used. Each plot consisted of 4 dwarf apple trees in a diagonal line across the bed. One or more guard rows were provided between each plot to minimise interplot contamination by spray drift. Plots in each block were arranged end to end in one bed. Blocks 1 and 2 were in bed 41 in the orchard. Blocks 3 and 4 were in bed 42 in the orchard.

Maintenance sprays

No overall insecticide sprays were applied to the experimental site during the study. A normal programme of fungicide sprays was applied by the grower (Appendix).

Meteorological records

Full records for the trial duration were taken from the EMR met station, which was approximately 16 km NNW of the trial site. The records (Figure 1) showed that, although a few days of dry weather occurred after the first spray application for the two spray treatments on 23 May, very heavy rainfall (total of 35 mm) occurred on 27 and 28 May. The air temperature during this period was also much lower than average. Rainfall causes high mortality of pear sucker nymphs, especially neonates. The heavy rainfall coincided with the main hatching period of neonates and caused a strong decline in nymph numbers which would have increased markedly had the weather remained dry. Rainfall also occurred on many days in the second half of June causing pear sucker populations to fall to very low levels by the end of the trial

Assessments

Mussel scale: On 14 April 2007, before the experiment commenced, the severity of mussel scale infestation on each tree was assessed prior to application of treatments (0 = no scales visible, 1 = a few, 2 = many, 3 = heavily infested). At harvest on 3-4 September, a sample of at least 60 fruits on each tree in each plot were picked and individually examined *in situ* for mussel scale infestation. The mussel scales present on each fruit, including the stalk, were counted.

<u>Natural enemies</u>: Two artificial refuges for earwigs, consisting of a 2 litre plastic drinks bottle with the base cut away and containing a loose roll of corrugated cardboard, to be deployed on in each plot (on two separate trees) for treatments B, E and L. Counts of the numbers of earwigs of each life stage in each bottle trap were made each time a spray treatment was applied plus at harvest. Earwigs were returned to refuge after counting.

<u>Phytotoxicity:</u> Determination of the phytotoxic effects of the treatments is not a central aim of this work. However, plots were inspected for any visual signs of phytotoxicity from the treatments at each spray occasion and at harvest.

Statistical analysis

Analyses of variance were done on the data. To stabilise variances, angular transformation was used for the percentage fruits infested and square root transformation for the mean numbers of scales per sampled fruit. The analyses were done with and without the pre-treatment infestation severity score as a covariate. In the case of the angular transformed percentage fruits infested, the covariance adjustment was positive and significant (P = 0.015) at the plot level so this analysis is the one reported; this indicates higher levels of final infestation for trees with higher initial levels. In the case of the square root numbers of scales per fruit, the covariate adjustment was close to statistical significance (P = 0.071) so for consistency the adjusted analysis is again reported. The adjustment was again positively related to initial score.

Results

Egg hatch and crawler emergence

The estimates of the percentage of eggs that had hatched were subject to substantial errors due to the variability of the data. To stabilise the data, much larger numbers of scales would need to have been examined than the sample size of 20, and the counting would have been excessively time consuming. However, the results do show the egg hatch had already commenced when the sampling was started on 25 April and that 100% hatch had been virtually reached by the end of May.

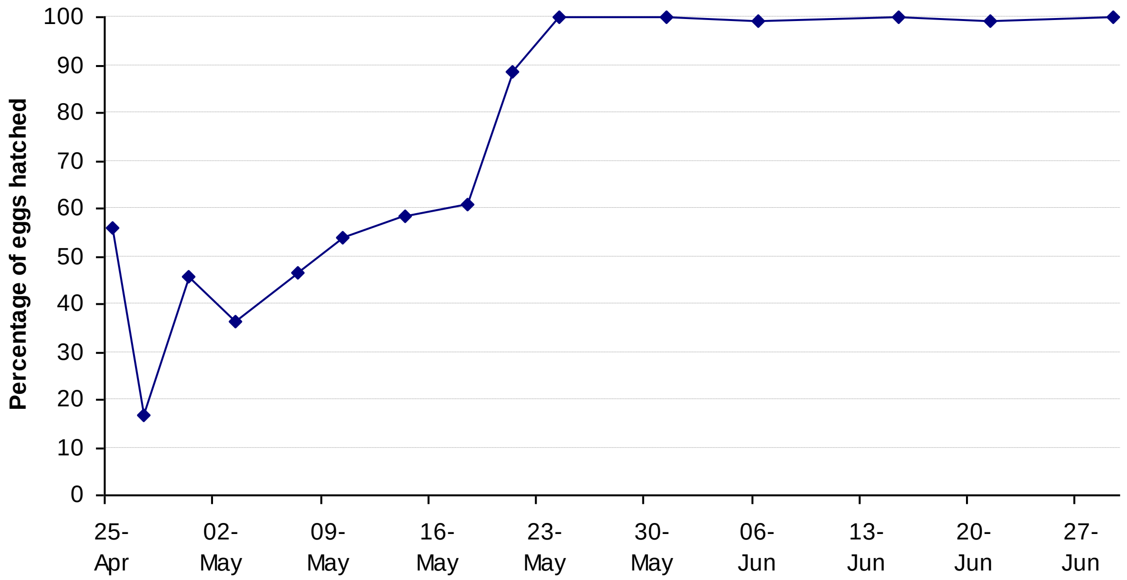


Figure 3. Estimates of percentage eggs hatched. Note the estimates were subject to large errors due to the variability in the data.

The sticky bands had an average circumference of 11.6 cm (8.6 cm and 14.6 cm for bands at top and bottom of the tree respectively). A total of 23 mussel scale crawlers (= 0.04/cm of trap/day) were captured between the 17 and 20 April when the traps were first deployed, indicating that the migration was just starting at this time. Numbers rose steeply until 25 April, followed by a temporary decline to 27 April. The cause of this temporary reduction in the increase in the rate of emergence is not clear. Little rainfall was recorded during the whole period and peak daytime temperatures on 26 and 27 April (16.1 and 16.7˚C, respectively) were higher than they had been over the previous 3 days (12.9, 12.4 and 13.8˚C, respectively). Numbers then rose steeply reaching a peak of 3530 (=19.0/cm/day) on 3 May before falling steeply in mid-May. A slight increase in the rate occurred at the end of May, after which the numbers fell to very low levels. Small numbers of nymphs continued to be captured till recording was terminated on 10 July. Thus, the main period of migration lasted for about a month from 23 April to 24 May, but with small numbers of crawlers continuing for a further 6 weeks. Similar numbers of nymphs were caught in total per cm of sticky band at the top of the tree (258/cm) and the bottom of the tree (290/cm). There was some evidence that the migration was slightly earlier at the top of the tree where peak numbers were recorded on 30 April than on the traps at the bottom of the tree where peak numbers were recorded on 3 May.

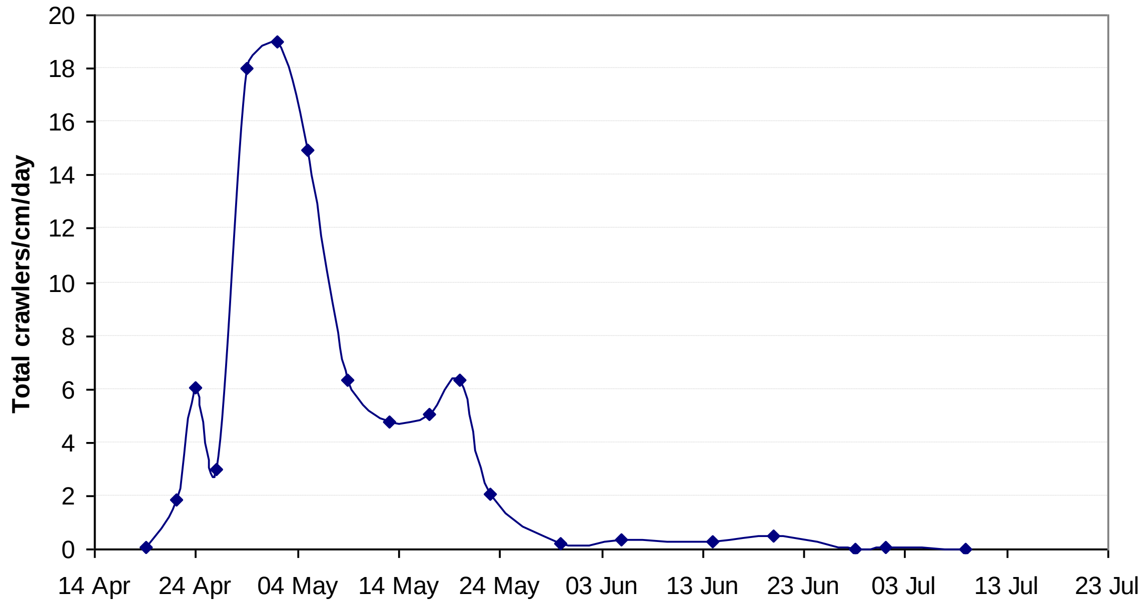


Figure 4. Mean numbers of crawlers captured per cm of sticky band per day.

Forecast of emergence

Cumulative temperature sums above a threshold of 8 ˚C from 1 January 2007 based on daily maximum and minimum air temperature records at the Met office weather station at East Malling Research are shown in Figure 4.

The accumulated sum reached the value of 151 DD > 8 which gave a predicted date of first emergence of 11 May 2007 (Figure 5). The sum reached the values of 190 and 229 DD > 8 for peak and 90% emergence on 16 and 24 May 2007. The actual first emergence, peak and 90% emergence dates were 23 April 3 May and 18 May respectively (Figure 6). Thus the model predictions were too late by 18, 13 and 6 days for the first, peak and 90% emergences, respectively.

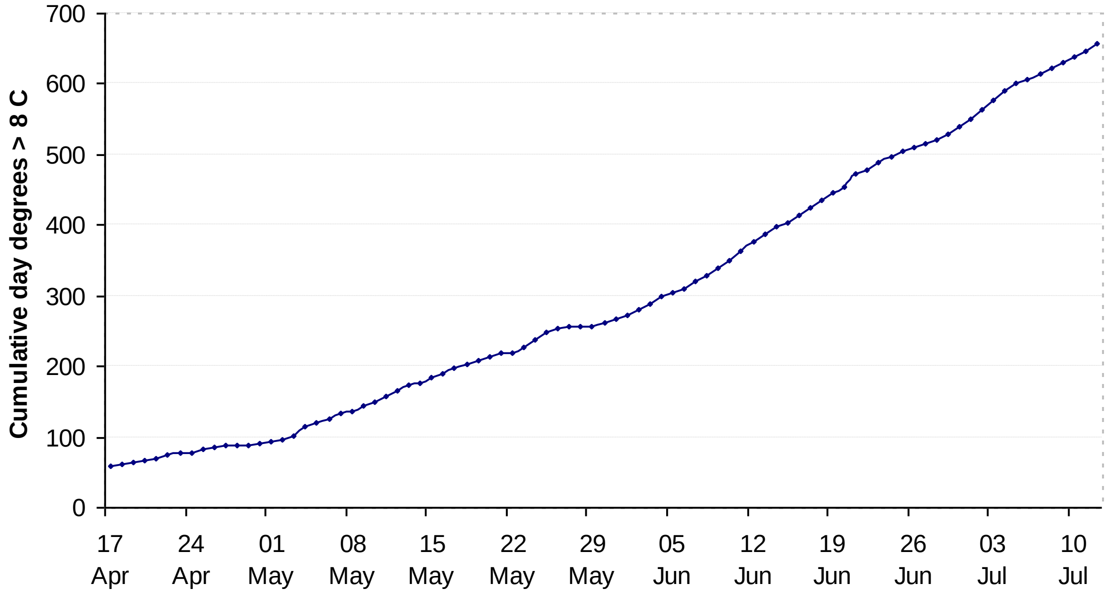


Figure 5. Cumulative temperature sums above a threshold of 8˚C from 1 January 2007 based on daily maximum and minimum air temperature records at the Met office weather station at East Malling Research

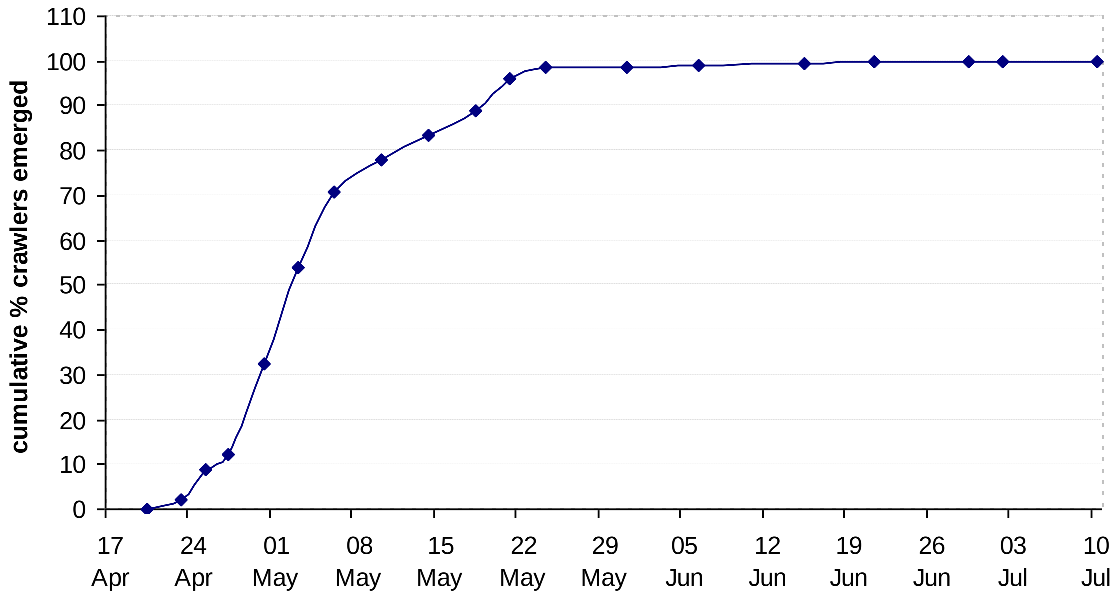


Figure 6. Cumulative % crawlers captured in sticky band traps

Efficacy of treatments

The analysis of variance of the angular transformed percentages of fruits infested with mussel scale at harvest showed highly significant treatment effects (Table 5). On the untreated control, 63.8% of fruits were infested. All the spray treatments except the Insegar at 2% emergence (treatment F) reduced the percentage fruits infested compared to the untreated control. Examining the effect of the 3 timings of the single sprays of Calypso, there was a clear improvement in control with increasing time of application, the spray at 98% emergence giving the greatest degree of control of these single Calypso spray treatments. However, the latest single Calypso spray only gave 88% control. The treatments comprising two sprays of Calypso both had a smaller percentage of fruits infested, significantly lower than the first two timings for single applications of Calypso. Examining the comparison between the 6 different products, each applied as two sprays at 40% and 98% emergence, the Calypso and Gazelle gave the best and similar results, reducing the percentage fruits infested by 94% on average. The Insegar gave the poorest results reducing the percentage fruits infested by 28%. Envidor, Dursban and Mainman reduced the percentage infestation by 72% on average.

Table 5. The percentage and angular transformed percentage fruits infested with mussel scale at harvest, covariate adjusted for the pre-treatment severity of infestation

Treatment (Product and timing in relation to crawler emergence)	% fruits infested with mussel scale at harvest	
	%	Ang (%)†
A. Calypso 2%	22.7	27.05 c
B. Calypso 40%	15.4	20.29 cd
C. Calypso 98%	7.7	13.57 de
D. Calypso 98% then + 2 wks	3.2	8.66 e
E. Calypso 40% then 98%	3.0	8.60 e
F. Insegar 2%	55.1	48.06 ab
G. Insegar 40% then 98%	45.9	42.20 b
H. Envidor 40% then 98%	18.7	23.88 c
I. Gazelle 40% then 98%	3.7	7.13 e
J. Dursban 40% then 98%	15.5	21.67 cd
K. Mainman 40% then 98%	20.0	25.29 c
L. Untreated	63.8	54.23 a
Fprob		<0.001
SED (31 df)		4.416
LSD (P = 0.05)		9.006

† Means followed by the same letter did not differ significantly in a Duncan's multiple range test (P = 0.05)

The analysis of variance of the square root numbers of mussel scales per sampled fruit also showed highly significant treatment effects (Table 6). The untreated control had an average of 3.6 scales per fruit at harvest. The single Calypso sprays at the 3 different timings reduced the numbers of scales per fruit by 91%. Although there were no significant differences between the individual, the latest timing (at 98% emergence) had the lowest mean number of scales per fruit.. Again, the two treatments that comprised two sprays performed better than the single Calypso spray treatments, but not significantly so. The two sprays of Insegar (G) reduced the numbers of scales per fruit significantly compared to the untreated control but the single spray (F) did not. The comparison between the 6 different products applied as two sprays at 40% then 98% emergence showed similar treatment effects as the percentage fruits infested variate.

Gazelle and Calypso gave the best results, reducing the numbers of scales per fruit by 98% on average. Envidor, Dursban and Mainman performed similarly, reducing the number giving partial control and reducing the numbers of scales per sampled fruit by 87% on average.

Table 6. The mean number and mean square root number of mussel scale per fruit at harvest, covariate adjusted for the pre-treatment severity of infestation.

Treatment (Product and timing in relation to crawler emergence)	Mean number of mussel scale per fruit at harvest	
	x	√x†
A. Calypso 2%	0.50	0.645 c
B. Calypso 40%	0.43	0.533 cd
C. Calypso 98%	0.07	0.296 cde
D. Calypso 98% then + 2 wks	0.05	0.174 de
E. Calypso 40% then 98%	0.03	0.173 de
F. Insegar 2%	2.81	1.584 ab
G. Insegar 40% then 98%	2.16	1.326 b
H. Envidor 40% then 98%	0.44	0.589 c
I. Gazelle 40% then 98%	0.06	0.141 e
J. Dursban 40% then 98%	0.45	0.561 cd
K. Mainman 40% then 98%	0.48	0.623 c
L. Untreated	3.60	1.784 a
Fprob		<0.001
SED (31 df)		0.1736
LSD (P = 0.05)		0.3540

† Means followed by the same letter did not differ significantly in a Duncan's multiple range test (P = 0.05)

Phytotoxicity

Determining possible phytotoxic effects of the treatments was not an objective of the work. All the products are approved for use on apple and are not known to be phytotoxic. No visual symptoms of phytotoxicity were observed during the experiment.

Predatory insects

Numbers of earwigs and other predatory insects in the artificial refuges were very small and effects of treatments on them could not be distinguished.

Conclusions

- In 2007 in the experimental orchard at Wares Farm, Linton, the main period of emergence and migration of mussel scale crawlers lasted for about a month from 23 April to 24 May 2007, but small numbers of crawlers continued to migrate for a further 6 weeks. The peak of the migration occurred on 3 May 2007. The duration of the migration at a high level was much longer than had previously been understood by UK growers and advisors
- Sticky traps consisting of bands of double sided sellotape round the trunks of untreated, infested trees proved very effective for monitoring crawler emergence and migration. At the peak of the migration, 19 crawlers were captured per cm of sticky band per day. Similar numbers of nymphs were caught in total in bands at the top of the tree as in bands the bottom of the tree (~50 cm above the ground). There was some evidence that the migration was slightly earlier at the top of the tree where peak numbers were recorded on 30 April than on the traps at the bottom of the tree where peak numbers were recorded on 3 May
- Predictions of first, peak and 90% crawler emergence were made based on the temperature sum model developed by Helsen et a. (1996) in the Netherlands. The accumulated sum reached the value of 151 Day Degrees > 8˚C which gave a predicted date of first emergence of 11 May 2007. The sum reached the values of 190 and 229 Day Degrees > 8˚C for peak and 90% emergence on 16 and 24 May 2007. The actual first emergence, peak and 90% emergence dates were 23 April 3 May and 18 May respectively. Thus the model predictions were too late by 18, 13 and 6 days for the first, peak and 90% emergences, respectively. Thus, the model did not give predictions of acceptable accuracy. The lateness of the predictions may possibly be because temperatures on the bark surface, which are exposed to direct sunshine, are substantially higher than air temperatures recorded by weather stations, where temperature sensors are held in a Stevenson's screen
- There was a clear improvement in mussel scale control with increasing time of

application of single sprays of Calypso, the spray at 98 % emergence giving the greatest degree of control, reducing the percentage fruits infested by 88% and the mean number of scales per fruit by 98%.

- The treatment comprising a single spray of Insegar at 2% emergence gave at best only minimal control of mussel scale
- The treatments comprising two sprays of Calypso both had a smaller percentages of fruits infested than the single spray treatments
- Of the 6 different products compared as two sprays at 40% and 98% emergence, the Calypso and Gazelle gave the best and similar results, reducing the percentage fruits infested by 94% on average (99% reduction in numbers of scales per fruit). Two sprays of Insegar gave the poorest results, reducing the percentage fruits infested by 28% (40% reductionin numers of scales per fruit). Two sprays of Envidor, Dursban or Mainman gave intermediate results, reducing the percentage infestation by 72% on average (87% reduction in numbers of scales per fruit)
- Overall, the results indicate that Gazelle and Calypso are the best products but two or more sprays may be required to give a high degree of control of heavy infestations of the pest
- The results suggest that the spray are best applied in the latter part of the migration (after 50% emergence) with an intervals between sprays of at least two weeks

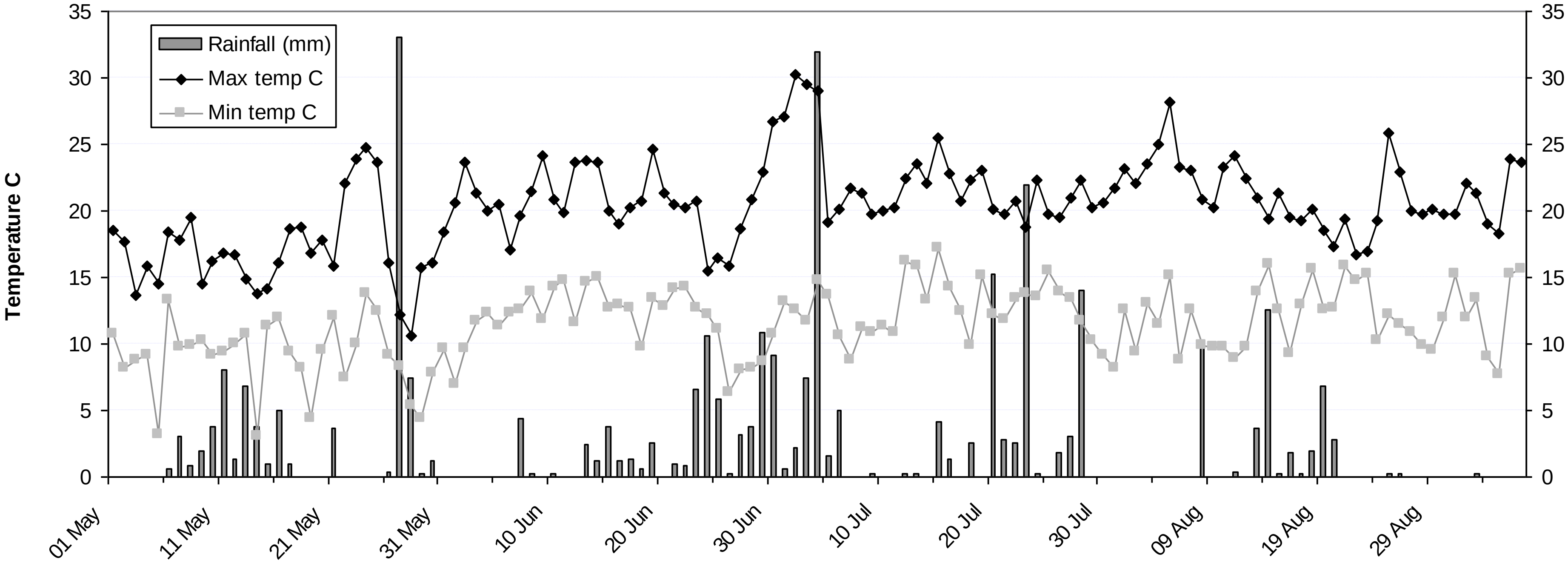
Acknowledgements

This work was funded by the Horticultural Development Council. We are most grateful to Brian Tompsett, Wares Farm, Linton, for providing the orchard for the experiment.

Reference

Helsen, H. H. M., Blommers, L. H. M. and Trapman, M. C. 1996. Timing observation and control of mussel scale, *Lepidosaphes ulmi*. IOBC wprs Bulletin 19(4), 145-149

Appendix



Appendix figure. Daily maximum and minimum air temperature (˚C) and rainfall amount (mm) at East Malling Research in 2007.