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Grower summary

Headline

- Based on a 2-year trial the best control of mussel scale can be achieved with two applications of ‘Calypso’ or ‘Gazelle’ two weeks apart towards the end of the crawler migration.

Background and deliverables

Since the demise of winter tar oil wash treatments, mussel scale has been increasing in importance in commercial apple orchards in the UK. A field study in 2007 (project TF 178) found that the main period of emergence and migration of mussel scale crawlers lasted for about a month from 23 April to 24 May 2007, with the peak migration 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. Predictions of crawler emergence using a Dutch ambient air temperature sum model were too late. It was hypothesised that the lateness of the predictions may be because temperatures on the tree bark surface, which is exposed to direct sunshine and absorbs and retains heat, are substantially higher than air temperatures recorded in a Stevenson’s screen. The 2007 study indicated that ‘Gazelle’ and ‘Calypso’ were the best products, but two or more sprays may be needed to give a high degree of control of heavy infestations of the pest. The results showed that sprays are best applied in the latter part of the migration (after 50% emergence) with a spray interval of at least two weeks. The overall aim of this research was to establish cost effective treatments for control of mussel scale on apple and;

1. determine the efficacy of winter treatments with ‘Certis Spraying Oil’, alone or in admixture with chlorpyrifos (‘Dursban’) or thaicloprid (‘Calypso’)
2. determine the effects of timing of application of thiacloprid in relation to crawler emergence (at first, 50%, 90% emergence, 90% emergence + 2 weeks, 90% emergence + 4 weeks)
3. determine whether the efficacy of thiacloprid can be enhanced by addition of a vegetable oil or a silicone adjuvant
4. determine the efficacy of a single spray of spirodiclofen (‘Envidor’) at 90% emergence
5. determine whether the Dutch mussel scale emergence model gives more accurate predictions if local bark surface temperature measurements are used

Summary of the project and main conclusions

A replicated experiment was done in a Cox orchard in Kent to evaluate insecticide spray treatments for control of mussel scale. Treatments included winter applications of ‘Certis Spraying Oil’, alone or in admixture with chlorpyrifos (‘Dursban’) or thiacloprid (‘Calypso’), a spray of ‘Calypso’ applied at 50%, 90%, 90% + 2 weeks and 90% + 4 weeks mussel scale crawler emergence, acetamiprid (‘Gazelle’) or spirodiclofen (‘Envidor’) at 90% emergence, the silicone wetter ‘Break Thru S240’ alone and an untreated control.

The numbers of crawlers emerging (caught in sticky band traps – see Figure 1) and number of unhatched eggs in scales were assessed twice weekly over the emergence period. The percentage fruit infested and the number of scales on each apple were assessed at harvest, and the number of scales per metre of shoot were assessed in the dormant period.

Figure 1. **Sticky band trap round trunk of tree to monitor numbers of migrating mussel scale crawlers, which can be seen in large numbers**

Emergence of mussel scale crawlers began on 1-6 May with the majority having emerged by the end of May. The main emergence period lasted a month and 90% crawler emergence was reached by 27 May. In the pesticide efficacy trials:

1. Winter treatments of mineral oils with or without insecticides did not control mussel scale on the fruits or shoots
2. The treatments that gave good control of the number of fruits infested with scale, the number of scales on each fruit, **and** scales on the shoots were one spray of ‘Calypso’ plus ‘Break-Thru’ at 90% emergence, or ‘Calypso’ or’ Gazelle’ (2007 trial) applied twice, two weeks apart at the end of the crawler migration (50% emergence onwards)
3. The addition of an adjuvant to ‘Calypso’ meant that only one spray was needed to achieve equivalent control
4. Single applications of ‘Envidor’ or the silicone wetter ‘Break Thru S240’ did not provide adequate control of mussel scale on the fruit or shoots
5. The Dutch air temperature sum model predicted the emergence of the crawlers more accurately than the tree bark temperatures on the north or south of the tree and was only 4 days early in predicting when to spray (90% emergence) compared to 11 and 20 days late on the north and south tree bark, respectively

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.

Action points for growers

- Two sprays of ‘Calypso’ or ‘Gazelle’ (two weeks apart), or a single spray of ‘Calypso’ with ‘Break Thru’ towards the end of the mussel scale crawler emergence, will achieve a significant reduction in the number of scales on harvested fruits.
- The Dutch air temperature sum model should be used to estimate the timing of spray applications.

Science Section

Introduction

Mussel scale (*Lepidosaphes ulmi*) is a common pest of apple (and sometimes pear) in the UK, and has become more prevalent in recent years. It occurs on other woody host plants, including cherry, plum, bilberry, currants, gooseberry, blackthorn, cotoneaster, hawthorn 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.

Adult female mussel scale are 2.0-3.5 mm long, flat and mussel shell–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 and pale yellowish-brown. The eggs are minute, oval and white and are protected 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 appears glistening and sticky, but later becomes unsightly with the growth of sooty mould fungi on the honeydew.

Life cycle

The first eggs hatch in late April and the first stage crawlers wander over the host plant settling on the bark and, sometimes, on the developing fruit. Each crawler moults to a second, then third instar nymph, both stages being sedentary and remaining in the same place, protected by the mussel-shaped scale formed from wax and the cast nymphal skin. In late August and September, each female lays up to 80 eggs beneath the scale, and 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 and 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 parasitoid 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 wasps do not constitute a significant or reliable regulatory mechanism. Predatory insects, including ladybird adults and larvae, mirids, anthocorids and 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 of crawlers to occur at 151 Day Degrees >8 ºC (after 1 January), 90% emergence at 229 Day Degrees >8 ºC (after 1 January). Mass egg hatch was predicted to occur at about 190 Day Degrees. Ninety percent hatch occurs at 230 Day Degrees and is considered to be the optimum timing for application of commonly used pesticides. Predictions of crawler emergence using a Dutch temperature sum model in the first years' trial (2007) were too late. It was hypothesised that the lateness of the predictions may be because temperatures on the bark surface, which is exposed to direct sunshine and absorbs and retains heat, are substantially higher than air temperatures recorded in a Stevenson's screen.

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 an infestation developing. Mussel scale populations tend to be greatest in old orchards where the pest has been allowed to increase without control over a number of years. 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 vital to time sprays correctly. According to Helsen *et al.* (1996) 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 (e.g. ‘Savona’) are the only insecticides approved for use on tree fruit crops in the UK for control of scale insects. However, treatment with fatty acids 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 (‘Dursban’, ‘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 establish cost effective treatments for control of mussel scale on apple and:

1. determine the efficacy of winter treatments with ‘Certis Spraying Oil’, alone or in admixture with chlorpyrifos (‘Dursban’, ‘Equity’ etc.) or thaicloprid (‘Calypso’)
2. determine the effects of timing of application of thiacloprid in relation to crawler emergence (at first, 50%, 90% emergence, 90% emergence + 2 weeks, 90% emergence + 4 weeks)

3. determine whether the efficacy of thiacloprid can be enhanced by addition of a vegetable oil or a silicone adjuvant
4. determine the efficacy of a single spray of spirodiclofen ('Envidor') at 90% emergence
5. determine whether the Dutch mussel scale emergence model gives more accurate predictions if local bark surface temperature measurements are used

Methods and materials

Site

The trial was done in beds 41, 42 and 43 of a four 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 ha^{-1}. Each bed contained approximately 350 trees.

Figure 1. Cox apple trees in the four row bed orchard used for the experiment, photographed on 12 May 2008

Treatments

Treatments included a winter applications of 'Certis Winter Oil', alone or in admixture with chlorpyrifos ('Dursban') or thiacloprid ('Calypso'), a spray of 'Calypso' applied at 50%, 90%, 90% + 2 weeks and 90% + 4 weeks mussel scale crawler emergence, acetamiprid ('Gazelle') or spirodiclofen (‘Envidor’) at 90% emergence, the silicone wetter ‘Break Thru S240’ alone and an untreated control (Table 1).

Table 1. Treatments. Emerg = percentage mussel scale crawler emergence

Treatment	Product	Active substance and formulation	Product dose ha^{-1}	No. of sprays	Timing of application	Date of application
A	'Dursban 4 EC'* + 'Certis Spraying Oil'**	chlorpyrifos + mineral oil	1 l 30 l	1	Mid winter	14/12/07
B	'Calypso' + 'Certis Spraying Oil'**	thiacloprid 480 g l^{-1} SC + mineral oil	375 ml 30 l	1	Mid winter	14/12/07
C	'Certis Spraying Oil'	mineral oil	30 l	1	Mid winter	14/12/07
D	'Calypso'	thiacloprid 480 g l^{-1} SC	375 ml	1	1st emerg	06/05/08
E	'Calypso'	thiacloprid 480 g l^{-1} SC	375 ml	1	50% emerg	21/05/08
F	'Calypso'	thiacloprid 480 g l^{-1} SC	375 ml	1	90% emerg	04/06/08
G	'Calypso'	thiacloprid 480 g l^{-1} SC	375 ml	1	2 weeks after 90% emerg	20/06/08
H	'Calypso'	thiacloprid 480 g l^{-1} SC	375 ml	1	4 weeks after 90% emerg	07/07/08
I	'Calypso'	thiacloprid 480 g l^{-1} SC	375 ml	2	50% emerg, 2 weeks after 90% emerg	21/05/08 and 20/06/08
J	'Gazelle'	acetamiprid 20% w/w SP	375 g	1	90% emerg	04/06/08
K	'Calypso' + 'Break-Thru S 240'	thiacloprid 480 g l^{-1} SC + silicone adjuvant	375 ml 5%	1	90% emerg	04/06/08
L	'Calypso' + 'Certis Spraying Oil'**	thiacloprid 480 g/l SC + mineral oil	375 ml 30 l	1	90% emerg	04/06/08
M	'Break Thru S 240'	silicone adjuvant	0.5%	1	90% emerg	04/06/08
N	'Certis Spraying Oil'**	mineral oil	30 l	1	90% emerg	04/06/08
O	'Envidor'	spirodiclofen 240 g l^{-1} SC	600 g	1	90% emerg	04/06/08
P	-	untreated	-	-	-	-

* 'Dursban 4' pre-blossom rate is half normal rate. ** 'Certis Winter Oil' (mineral) applied at 3% in 1000 l
Note 'Calypso' has a max. concentration of 25 ml l^{-l} and a max single application of 375 ml ha^{-1}, but 375 in 500 l was used in the 2007 trial

Monitoring egg hatch and crawler emergence to time sprays

Twice weekly, from 7 April to 4 July, a sample of 10 mature (overwintered) scales on shoots and spurs were collected and the numbers of unhatched eggs counted under a binocular microscope in the laboratory. This enabled estimates of the proportion of eggs that had hatched to be made. Five pairs of sticky traps were also deployed as ring bands round the trunks/branches of five 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 towards the base of the tree, approximately 50 cm above the ground. The bands were made from double sided sellotape (Fig. 2). 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. Graphs of emergence and number of eggs remaining in scales 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**

Temperature sum model

On 26 November 2007, two temperature loggers were deployed on the trunks of apple trees to take hourly readings of tree surface temperature. A temperature logger was also deployed in a Stevenson's screen, in the orchard, to monitor hourly air temperatures. Day degree sums >8 ºC after 1 January were calculated from daily maximum and minimum temperature readings, calculated using the triangulation method. The temperature sums at the observed dates of emergence were compared with the temperature sum predictions of the Dutch model. In the temperature sum simulation model developed by Helsen *et al.* (1996), first emergence was forecast to occur at 151 DD>8 ºC after 1 January and 90% emergence at 230 DD>8 ºC after 1 January.

Spray application

The average tree canopy height recorded at time of the first spray application was 1.8 m. The Crop Adjustment Factor (CAF) of the trees was 1.0. Winter spray applications were applied at 1000 l ha^{-1} with a Birchmeier motorised air-assisted knapsack sprayer fitted with a red Micron spray restrictor. All other sprays were applied at volumes of 500 l ha^{-1} with a pink Micron spray restrictor. Pre-treatment calibration showed that the sprayer delivered spray at a flow rate of 780 (red), 680 (pink) ml $minute^{-1}$, so each tree was sprayed for a duration of 20 (red) and 12 (pink) seconds to deliver a volume of 272 (red) 136 (pink) 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 within 11% of the required volume (Table 2).

Table 2. Percentage accuracy of spray applications. Note: volumes were measured to the nearest 100 ml

Spray Date											
14 Dec 2007		6 May 2008		21 May 2008		4 June 2008		20 June 2008		7 July 2008	
Trt	%	Trt	%	Trt	%	Trt	%	Trt	%	Trt	%
A	111	D	104	E	107	F	100	G	97	H	108
B	107			I	107	J	97	I	97		
C	98					K	100				
						L	102				
						M	100				
						N	102				
						O	102				

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 (Table 3).

Table 3. Air temperature and humidity conditions at the time of spray application

Date	At beginning of spray applications					At end of spray applications				
	h	Temp (˚C)			Wind speed (km h^{-1})	h	Temp (˚C)			Wind speed (km h^{-1})
		Dry bulb	Wet bulb	RH%			Dry bulb	Wet bulb	RH%	
14 Dec 07	1430	4.5	4.0	92.5	0	1615	4.5	4.0	92.5	0
6 May 08	1830	20.0	16.0	67.0	0	1850	20.0	16.0	67.0	0
21 May 08	0855	16.0	12.5	62.5	0	0930	17.0	14.0	72.0	0
4 June 08	1155	19.0	16.5	76.5	0	1410	20.6	15.6	60.0	0
20 June 08	1130	17.0	16.0	91.0	2	1210	18.5	14.5	64.0	0
7 July 08	0730	15.0	13.0	79.0	0	0800	12.0	11.3	92.5	0

Experimental design and layout

A randomised complete block experimental design with four replicate plots of each treatment was used. Each plot consisted of four 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; block 3 in bed 42, and block 4 in bed 43 of the orchard.

Maintenance sprays

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

Meteorological records

Full weather records for the trial duration were taken from the EMR met station, which was approximately 16 km NNW of the trial site. The air temperature records are shown plotted with the north and south tree bark temperatures in the appendix figures (1&2).

Assessments

<u>Mussel scale</u>: On 26 November 2007, before the application of treatments, the severity of mussel scale infestation on each tree was assessed (0 = no scales visible, 1 = a few, 2 = many, 3 = heavily infested). At harvest on 11-12 September, a sample of 50 fruits on each tree in each plot were picked and individually examined for mussel scale infestation. The scales present on each fruit, including the stalk, were counted. After harvest, five new shoots (shoots that had grown in 2008) per tree on all plots were pruned and then assessed under a microscope in the laboratory. The length of each shoot was also measured.

Natural enemies: 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, was deployed in each plot (on two separate trees) for treatments B ('Calypso' plus 'Certis Winter Oil' - midwinter), E ('Calypso' at 50% emergence), L ('Calypso' plus mineral oil at 90% emergence) and P (control). In order to see if 'Calypso' had negative effects on population of natural predators counts of the numbers of potential predators were done on 8 May, 5 June and 9 July 2008.

Phytotoxicity: Determination of the phytotoxic effects of the treatments was 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 the pre-treatment infestation severity score as a covariate. However, the covariance adjustments were not significant.

Results

Egg hatch and crawler emergence

The mean number of eggs in 10 scales was highly variable (Fig. 3). However, the results do show that almost 100% hatch had been reached by the end of May.

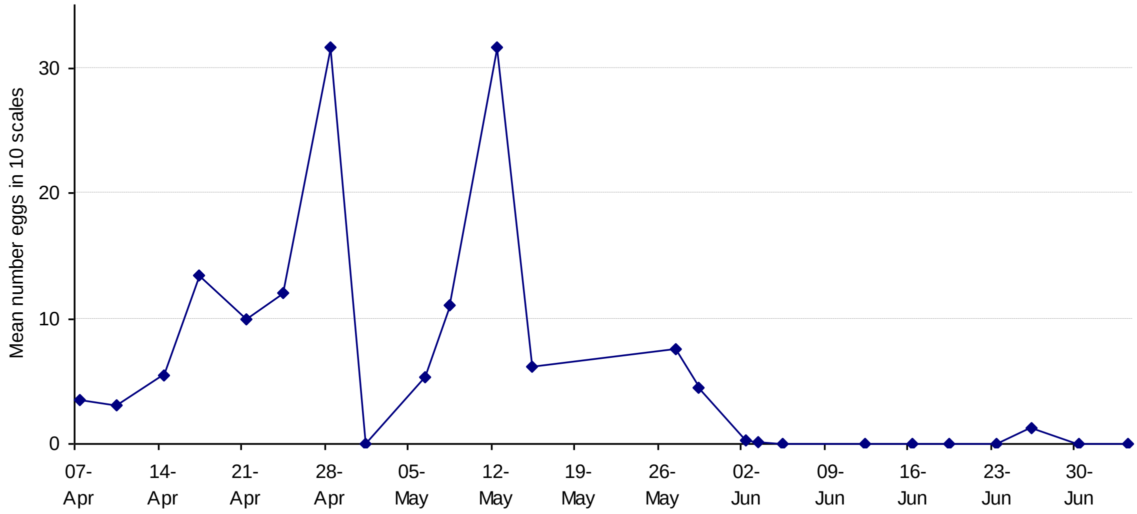

Figure 3. Mean number of eggs in 10 scales recorded twice weekly. The counts were highly variable

The sticky bands (deployed on 7 April) had an average circumference of 14.3 cm (9.5 cm and 19.1 cm at top and bottom of the tree, respectively). No mussel scale crawlers were observed until 1-6 May, when 31 crawlers (= 0.04/cm of trap/day) were captured. Numbers rose steeply until 22 May (1710 crawlers, 11.93/cm/day), with a temporary decline on 19 May. The latter also occurred in the first year of the spray trial (2007), but the cause is not known. The population then fell steeply at the end of May. Thus, the main period of migration lasted for about a month from the beginning to the end of May, compared to the previous year when the migration occurred from 23 April to 24 May. 90% emergence, when it is recommended that sprays are applied, had been reached by 27 May. Small numbers of nymphs continued to be captured until recording was terminated on 04 Jul. More than double the number of crawlers were captured at the bottom of the trees (146/cm tape) compared to the top of the trees (69/cm tape). In addition, in contrast to the previous year, the crawlers first emerged from the bottom of the tree before the top of the tree.

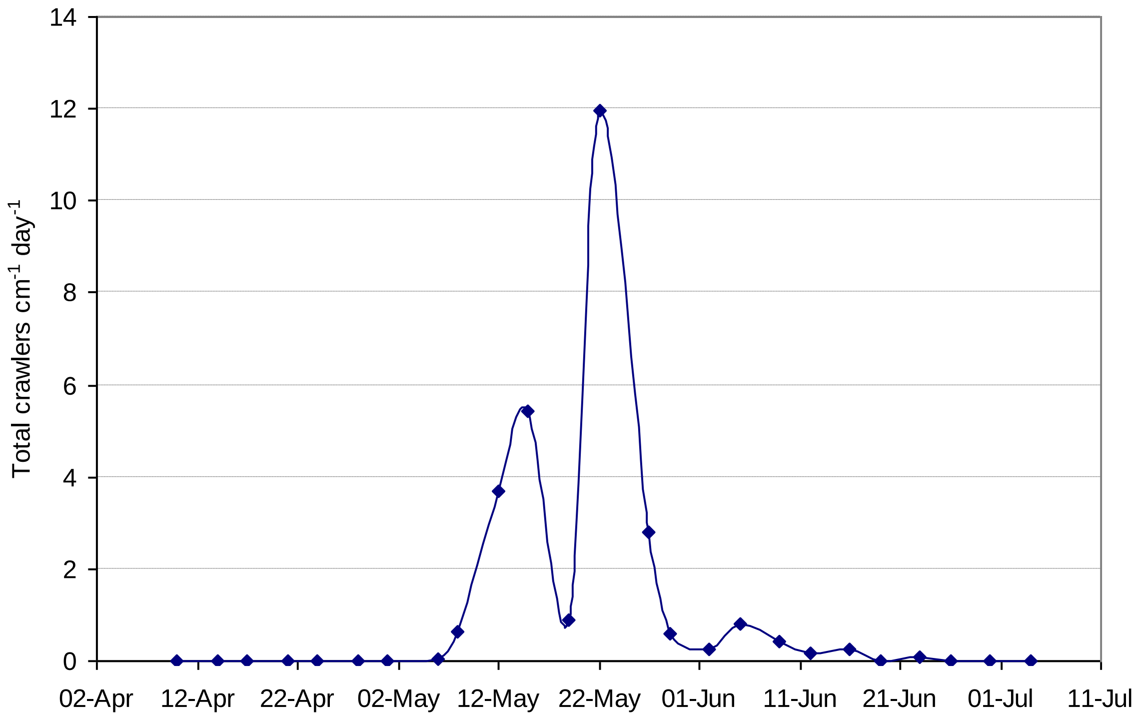

Figure 4. **Mean numbers of crawlers captured cm^{-1} of sticky band per day**

Forecast of emergence

Cumulative temperature sums above a threshold of 8 ˚C from 1 January 2008 based on daily maximum and minimum air temperature records at the East Malling Research meteorological station are shown in Fig. 5. Occasionally, the data loggers attached to the bark on the trunk of the tree failed to record if rain entered (South data logger; 8-9, 17-20 April, 28 May, North data logger; 7-21 April, Appendix Fig. 2), so mean temperatures for these days were calculated by plotting the logger temperature against the ambient air temperature and using the regression equation ($y = 1.057x + 0.7292$, $y = 1.0515x - 0.0398$, respectively). Generally the temperature on the south side of the tree was higher than the north, followed by air temperatures (Fig. 5).

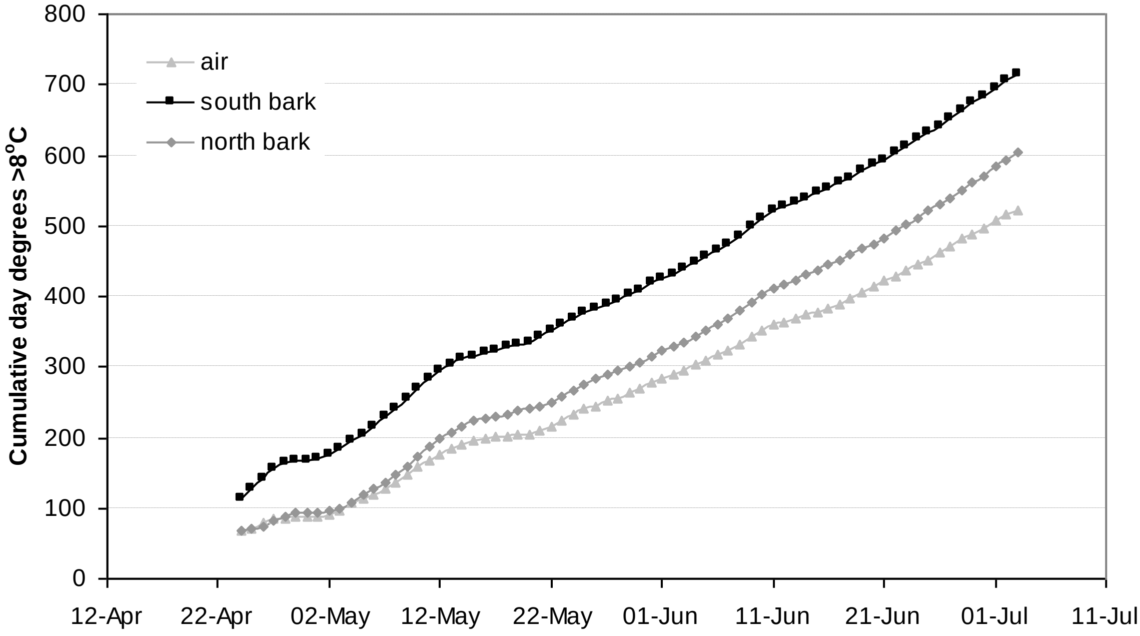

Figure 5. **Cumulative temperature sums above a threshold of 8 ˚C from 1 January 2008 based on daily maximum and minimum air temperature records from the Met office weather station at EMR**

The accumulated sum of day degrees >8 °C predicted by the model (Fig. 5) were compared to the actual emergence dates (Fig. 4). The model predictions for the first crawler emergence using the south bark data were 4-6 days early, and 2-7 days and 3-8 days later for the north bark and ambient air temperature, respectively (Table 4).

The actual peak emergence date was 8-19 days later than predicted by the model using the three temperature measurements (Fig. 6, Table 4). The actual 90% emergence date, the date at which insecticidal sprays are to be applied, was also later than predicted (20, 11 and 4 days for the south bark, north bark and air temperatures, respectively). However, the air temperature gave the most accurate prediction, compared to the tree bark temperatures.

Table 4. **Actual and model predicted dates of first, peak and 90% emergence of mussel scale crawlers**

Crawler emergence stage	Model accumulated sum degree days > 8°C	Predicted model date			Actual date
		Air	North bark	South bark	
First	151	9 May	8 May	27 April	6 May
Peak	190	14 May	11 May	3 May	22 May
90%	229	23 May	16 May	7 May	27 May

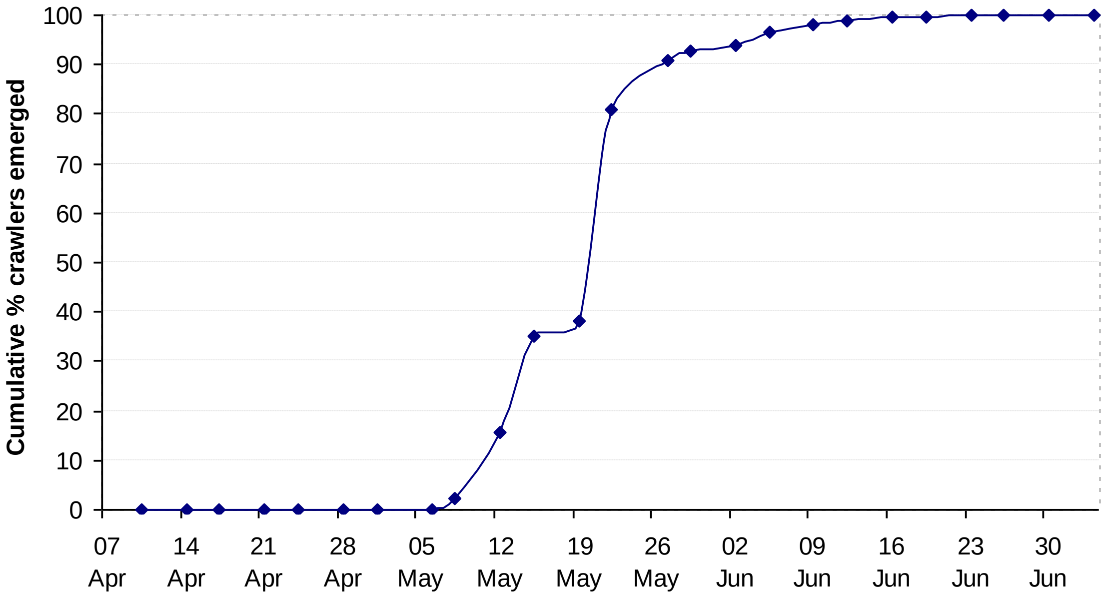

Figure 6. Cumulative percentage crawlers captured in sticky band traps

Efficacy of treatments

The analysis of variance of the angular transformed percentages of fruits infested with mussel scale at harvest showed significant treatment effects (Table 5). On the untreated control, 35% of fruits were infested. Three main groupings of treatments occurred. In the first, winter oil treatments (with and without chlorpyrifos or thiacloprid), thiacloprid 4 weeks after 90% emergence, 'Break-Thru', 'Certis Winter Oil' and spirodiclofen alone did not reduce the percentage of apples infested with mussel scale. In the second group, thiacloprid at first emergence, 90% emergence or 2 weeks after 90% emergence and thiacloprid plus 'Certis Spraying Oil' at 90% emergence were more effective than no treatment. By far the most effective treatments, which reduced the number of apples infested to below 1-4.5%, were thiacloprid at 50%, or 50% and then 2 weeks after 90% emergence, or thiacloprid plus 'Break-Thu' at 90% emergence or acetamiprid at 90% emergence (Table 5 and Fig. 7).

Table 5. The percentage and angular transformed percentage fruits infested with mussel scales 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. chlorpyrifos + mineral oil - mid winter	23.94	28.61	a
B. thiacloprid + mineral oil - mid winter	29.12	31.71	a
C. mineral oil - mid winter	34.31	34.28	a
D. thiacloprid – emerg	12.25	18.90	b
E. thiacloprid - 50% emerg	4.5	9.94	c
F. thiacloprid - 90% emerg	16.88	23.03	b
G. thiacloprid - 2 weeks after 90% emerg	13.75	20.09	b
H. thiacloprid - 4 weeks after 90% emerg	25.25	28.42	a
I. thiacloprid - 50% emerg, 2 weeks after 90% emerg	0.88	3.06	c
J. acetamiprid - 90% emerg	3.81	9.49	c
K. thiacloprid + silicone adjuvant - 90% emerg	2.25	6.13	c
L. thiacloprid + mineral oil - 90% emerg	10.38	16.94	b
M. silicone adjuvant - 90% emerg	23.06	27.79	a
N. mineral oil - 90% emerg	25.06	28.30	a
O. spirodiclofen - 90% emerg	32.19	34.77	a
P. untreated	35.06	36.08	a
Fprob		<0.001	
SED (44 df)		4.307	
LSD (P = 0.05)		8.680	

† Covariate adjusted for the pre-treatment infestation severity score
b significantly less than the untreated control
c significantly less than the treatments labelled b

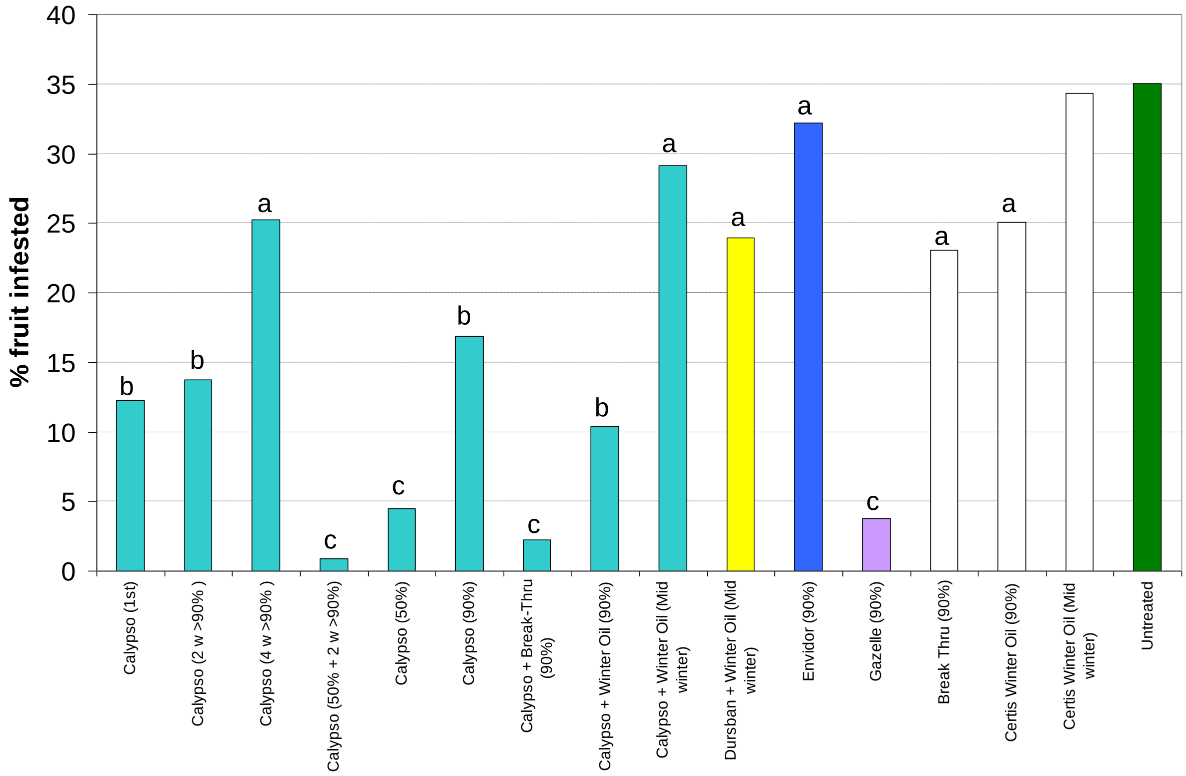

Figure 7. **Percentage of fruit infested with mussel scales at harvest. Products are listed by trade names. Different letters denote significant differences**

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 1.4 scales per fruit at harvest.

The most effective treatments at reducing the numbers of mussel scale on each fruit were thiacloprid plus ‘Break-Thru’ at 90% emergence or thiacloprid applied at 50% emergence and then 2 weeks after 90% emergence (0.05 and 0.02 scales per fruit, respectively).

Table 6. **The mean number and mean square root number of mussel scales per 100 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 100 fruits at harvest		
	x	√x†	
A. chlorpyrifos + mineral oil - mid winter	65.5	7.26	a
B. thiacloprid + mineral oil - mid winter	101.9	8.98	a
C. mineral oil - mid winter	167.4	10.95	a
D. thiacloprid – emerg	30.3	4.62	b
E. thiacloprid - 50% emerg	12.0	2.27	bc
F. thiacloprid - 90% emerg	44.8	5.78	b
G. thiacloprid - 2 weeks after 90% emerg	38.9	5.22	bc
H. thiacloprid - 4 weeks after 90% emerg	92.7	8.19	a
I. thiacloprid - 50% emerg, 2 weeks after 90% emerg	1.5	0.76	c
J. acetamiprid - 90% emerg	7.7	2.23	bc
K. thiacloprid + silicone adjuvant - 90% emerg	5.1	1.48	c
L. thiacloprid + mineral oil - 90% emerg	21.1	3.79	b
M. silicone adjuvant - 90% emerg	78.1	7.89	a
N. mineral oil - 90% emerg	68.0	7.07	a
O. spirodiclofen - 90% emerg	130.4	10.74	a
P. untreated	137.3	10.65	a
Fprob		<0.001	
SED (44 df)		1.897	
LSD (P = 0.05)		3.823	

† Covariate adjusted for the pre-treatment infestation severity score
b significantly less than the untreated control
c significantly less than the treatments labelled b

The analysis of variance of the angular transformed percentages of shoots infested with mussel scale after harvest showed significant treatment effects (Table 7 and Fig. 8). On the untreated control the number of scales per metre of shoot was 65.

The most effective treatments at reducing the number of scales on shoots were thiacloprid applied at 50% emergence, or 50% emergence and 2 weeks after 90% emergence, or thiacloprid in admixture with ‘Break-Thru’ at 90% emergence. Treatments that were not quite as effective, but that gave some control of mussel scale crawlers on shoots were acetamiprid or spirodiclofen at 90% emergence, thiacloprid plus ‘Certis Spraying Oil’ at 90% emergence or ‘Break-Thru’ alone at 90% emergence.

Table 7. The number and square root transformed numbers of mussel scales per metre of shoot after harvest

Treatment (Product and timing in relation to crawler emergence)	number of mussel scales/m shoot after harvest		
	number	√x	
A. chlorpyrifos + 'Certis Spraying Oil' - mid winter	36.4	5.075	a
B. thiacloprid + 'Certis Spraying Oil' - mid winter	49.8	6.156	a
C. 'Certis Spraying Oil' - mid winter	45.2	5.568	a
D. thiacloprid – emerg	38.3	5.176	a
E. thiacloprid - 50% emerg	17.1	2.783	c
F. thiacloprid - 90% emerg	43.1	5.259	a
G. thiacloprid - 2 weeks after 90% emerg	34.5	4.557	a
H. thiacloprid - 4 weeks after 90% emerg	55.4	6.093	a
I. thiacloprid - 50% emerg, 2 weeks after 90% emerg	6.35	1.595	c
J. acetamiprid - 90% emerg	28.5	4.138	b
K. thiacloprid + 'Break-Thru' - 90% emerg	7.7	1.379	c
L. thiacloprid + 'Certis Spraying Oil' - 90% emerg	33.2	4.201	b
M. 'Break-Thru' - 90% emerg	35.0	4.818	B
N. 'Certis Spraying Oil' - 90% emerg	42.0	5.256	A
O. spirodiclofen – 90% emerg	21.8	3.538	B
P. Untreated	64.9	6.968	A
Fprob		<0.001	
SED (45 df)		0.9660	
LSD (P = 0.05)		1.9455	

b significantly less than the untreated control
c significantly less than the treatments labelled b

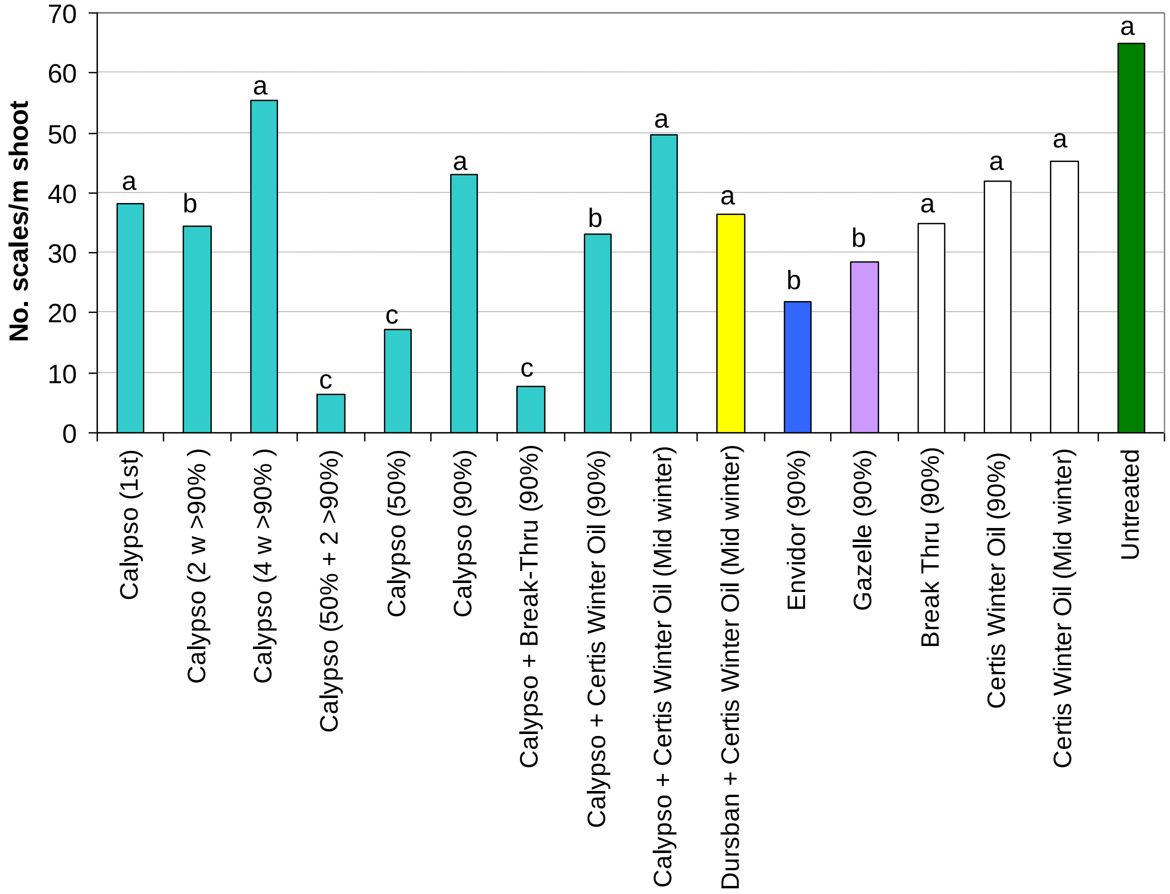

Figure 8. **Number of mussel scales per metre shoot sampled after harvest. Products are listed by trade names. Different letters denote significant differences**

For all assessments, none of the treatments applied in mid winter, with or without insecticides gave significant control of mussel scale on the fruits or shoots (Tables 5, 6 and 7).

Phytotoxicity

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 predators (spiders, earwigs, ants and syrphids) in the bottle traps were very low, but there were no detectable treatment effects. However, more syrphid pupae were present in the traps on 9 July compared to 8 May or 5 June (ANOVA $\log_{10}$ transformed data; P=0.04, lsd = 0.02501, sed= 0.01257). It is not know whether these insects are important predators of mussel scale.

Conclusions

Emergence of mussel scale crawlers began on 1-6 May with the majority having emerged by the end of May. The main emergence period lasted a month and 90% crawler emergence was reached by 27 May. In the pesticide efficacy trials:

1. Winter treatments of mineral oils with or without insecticides did not control mussel scale on the fruits or shoots
2. The treatments that gave good control of the number of fruits infested with scale, the number of scales on each fruit, <u>and</u> scales on the shoots were one spray of 'Calypso' plus 'Break-Thru' at 90% emergence, or 'Calypso' or 'Gazelle' (2007 trial) applied twice, two weeks apart at the end of the crawler migration (50% emergence onwards)
3. The addition of an adjuvant to 'Calypso' meant that only one spray was needed to achieve equivalent control
4. Single applications of 'Envidor' or the silicone wetter 'Break Thru S240' did not control of mussel scale on the fruit or shoots
5. The Dutch air temperature sum model predicted the emergence of the crawlers more accurately than the tree bark temperatures on the north or south of the tree and was only 4 days early in predicting when to spray (90% emergence) compared to 11 and 20 days late on the north and south tree bark, respectively

Hence, two sprays of 'Calypso' or 'Gazelle' (two weeks apart), or a single spray of 'Calypso' with 'Break Thru' towards the end of the mussel scale crawler emergence will achieve a significant reduction in the number of scales on harvested fruits and shoots. The Dutch air temperature sum model should be used to estimate the timing of spray applications.

Acknowledgements

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Reference

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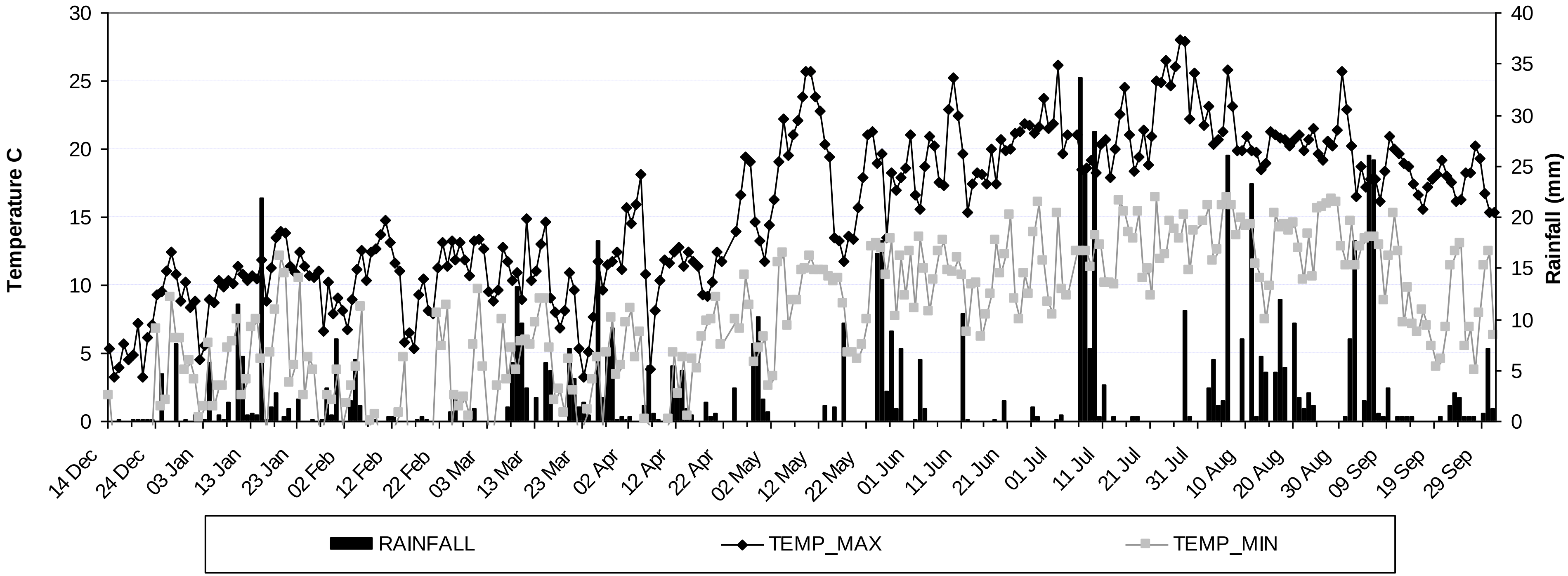
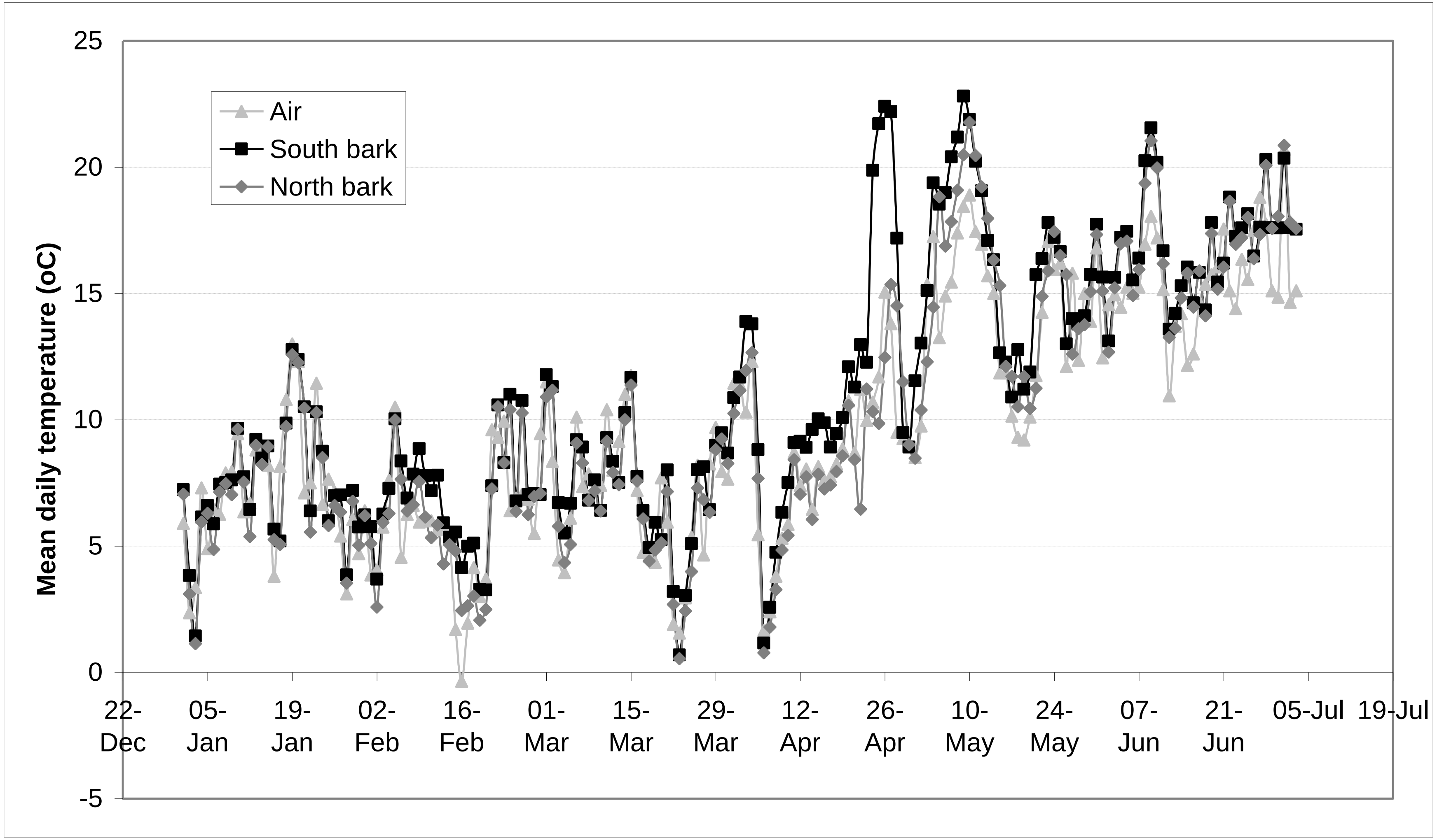
APPENDIX



Appendix Figure 1. Daily maximum and minimum air temperature (˚C) and rainfall amount (mm) at East Malling Research in 2008



Appendix Figure 2. **Daily maximum and minimum air temperature (EMR weather station) and temperatures of the north and south side of the tree bark (˚C) in 2008**