Project title:	Development of temperature degree-based models to predict pest development on strawberry for optimisation of control strategies
Project number:	SF 114
Project leaders:	Prof Xiangming Xu, Dr Jean Fitzgerald East Malling Research
Report:	Annual Report, Year 2
Previous report:	Annual Report, Year 1
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Date project commenced:	01/04/2010
Date project completed **(or expected completion date):**	31/03/2013

AUTHENTICATION

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

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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations

CONTENTS

GROWER SUMMARY

Headline

- Models for predicting development of tarsonemid mites and strawberry blossom weevils have been developed.

Background and expected deliverables

Strawberries are very susceptible to many pests, including European tarnished plant bug, strawberry blossom weevil, western flower thrips, aphids and tarsonemid mite. Some developmental stages of pests may be more susceptible to insecticides than others; information on when the most susceptible stages are present would enable more effective pesticide targeting. For pests in general (unlike diseases), the developmental rate is mostly related to temperature; mathematical models are used to describe such temperature-developmental-rate relationships.

Diapausing adults of European tarnished plant bugs (capsids) overwinter on weeds or crop debris. In the UK, the first generation of the pest is believed to develop on weeds, and adults from this generation disperse into strawberry where a second (and possibly a third) generation occurs. The dispersal into strawberry has generally been at the time of flowering of everbearer strawberries. Recent observations, however, suggest that capsids may disperse to and cause damage to many other crops, including June-bearerer strawberry, raspberry and blackberry, at much earlier times than previously reported, possibly because of warm winters and springs.

A current Hort-LINK project HL0191 (SF 94) is focusing on the development of a holistic integrated pest and disease management (IPDM) system for production of strawberries which does not rely on intensive use of fungicides and insecticides during flowering and fruit development. In a separate Hort-LINK project HL1107 (SF 120), a model for predicting western flower thrips development is also being developed.

There is one key expected deliverable from this project:

1. A model forecasting capsid development on strawberry developed and ready to be used by growers (together with models for other strawberry pests and diseases).

Summary of the project and main conclusions

Models have been developed which predict the phenology of strawberry tarsonemid mite and blossom weevil and incorporated into a computer programme that already contains models for strawberry grey mould, powdery mildew, western flower thrips and capsids. All pest models need to be further improved, especially in relation to pest development in early spring.

New biological data on capsid development have been obtained in order to improve the capsid model. Regular sampling for the pest in weeds and strawberry fields has provided more information on the development of the pest related to temperature; these data will be used for validation of the model.

Financial benefits

It is too early to identify any financial benefits emanating from this project.

Action points for growers

- No action points have arisen from this work so far.

SCIENCE SECTION

Introduction

Strawberries are very susceptible to many pests and diseases, most of which cannot currently be effectively controlled by non-pesticidal means. These include botrytis grey mould, mildew, blackspot, European tarnished plant bug (capsid), strawberry blossom weevil, western flower thrips, aphids and tarsonemid mites. Correct timing/targeting of control strategies and decisions on whether intervention is needed (based on interpretation of pest monitoring or pest thresholds) depend on our understanding of pest development in relation to climatic conditions. Some developmental stages of pests may be more susceptible to insecticides than others and information on when the most susceptible stages are present would enable more effective pesticide targeting. For pests in general, unlike diseases, the developmental rate is mostly related to temperature; mathematical models are used to describe such temperature-developmental-rate relationships. These relationships will be different for different insect and mite species.

A current Hort-LINk project HL0191 (SF 94) is focusing on the development of a holistic integrated pest and disease management system strawberries which does not rely on intensive use of fungicides and insecticides during flowering and fruit development. In this Hort-LINK project, simple forecasting models for botrytis and powdery mildew are being developed and implemented as a computer programme; the research work on pests in the HL0191 project focuses on developing alternative non-pesticidal control methods.

The use of forecasting models would increase the understanding of when pests are likely to arrive in crops and how quickly they will develop when there. It may be possible to use this information to develop treatment thresholds for the pest. One simple-yet-useful model is that based on degree-days. These models often need a base temperature (i.e. the minimum temperature required for development) from which to accumulate degree days. Sometimes a maximum temperature may also be required to stop accumulating degree days (i.e. the maximum temperature that the insect can survive, reproduce or develop). Operating temperature-based models (e.g. degree-days) is relatively cheap and straightforward since it only needs temperature as an input, which can be provided by cheap and easy-to-use data loggers. A further advantage is that temperature can be forecast relatively accurately for 24-48 h and such forecasts can be incorporated into pest prediction models.

In another Hort-LINK project HL1107 (SF 120), a model is being developed that predicts population development of western flower thrips (WFT). This model has also been incorporated with the disease models.

In the present project, the aim is to develop models for other key strawberry pests, focusing on capsid. In addition to collecting data on capsid development in relation to temperatures for developing and validating the model, an understanding of the overwintering behaviour of this pest is also required. Diapausing adults of capsid overwinter on weeds or crop debris and in this state they do not lay eggs. Increasing daylength and temperature enable the insects to become active again. In the UK the first generation of the pest is believed to develop on weeds, and adults from this generation disperse into strawberry where a second (and possibly a third) generation occurs. The dispersal into strawberry has generally been at the time of flowering of everbearer strawberries. Capsids feeding on developing fruits cause the typical 'cat face' damage seen on everbearing strawberries. Recent observations however, suggest that capsids may disperse to, and cause damage to, many other crops, including June-bearer strawberry, raspberry and blackberry at much earlier times than previously reported, possibly because of warm winters and springs.

The work in the second year of this project was divided into two parts: (1) developing predictive models for tarsonemid mite and blossom weevil, and (2) conducting experiments to obtain further data for developing and validating the capsid model.

Materials and methods

Development of prediction models

Models have been developed for predicting the phenology of tarsonemid mites and blossom weevils, simulating population development from overwintering adults onwards. The models use either hourly or daily temperature data to estimate pest development. These two models were developed based on the data collected recently at EMR (Easterbrook *et al.*, 2003).

As reported in Year 1, several key assumptions have been made when developing models for the capsid, tarsonemid mite and blossom weevil, particularly concerning pest development in the early spring. More data is beingcollected in early spring 2012 in order to improve the capsid model (see below).

Experimental work with capsids

Field sampling - Weeds

Sweep samples were taken on weed plots between 16 March and 22 September 2011. A standard sample was 20 passes over the selected vegetation with a 50 cm diameter sweep net. If the sample size was less than this the number of passes was recorded to enable comparisons over time to be made. Multiple samples were taken on each date and the site and main weed species present were recorded. The numbers of *Lygus rugulipennis* nymphs (with each developmental stage recorded separately) and adults caught in sweep samples were identified and recorded in the laboratory. Total numbers recorded on each sample date were calculated.

Field sampling - Strawberry

Tap samples were taken on an everbearer strawberry planting (DM 183) at EMR between April and September; the cultivar was Evie 2. This strawberry planting was not polythene tunnelled. The strawberry plants were tapped over a white circular tray and the numbers of *Lygus rugulipennis* nymphs (with each developmental stage recorded separately) and adults caught were recorded in the field. Tap samples were also taken on a commercial strawberry planting, cultivar Amesti from April to August. This planting was tunnelled as in normal commercial practise.

Field sampling - Pheromone trap catches

Pheromone traps were placed in a weed strip at EMR on 16 March 2011 and numbers of males caught in the traps were counted until early October. Traps were also monitored on a commercial strawberry planting in 2011, cultivar Amesti. In 2012 traps were put out early in the season at EMR, from 2 February to 21 March. In 2012 the traps were placed in two strawberry crops and in a grassy orchard area next to an old weed plot that had been ploughed in but may have been an over-wintering site for the capsids.

Laboratory development studies

Rates of development of nymphal stages of *L. rugulipennis* on plant material in the laboratory were determined. The development of *L. rugulipennis* nymphs was monitored until adulthood under four temperature regimes. Adult females were allowed to lay eggs in strawberry plants (cv. Evie-2 or Flamenco) or cut green beans in a culture cage with a 14:10 light:dark regime at 20°C. Nymphs from these cultures were collected and used in the rearing experiments; nymphs were also collected from the field. The instar (developmental stage) of the nymphs at collection was recorded. The nymphs were then held individually in small Perspex boxes (16 x 10 x 8 cm approx). Each box contained two pieces of fine green bean that were cut into 4 cm lengths and then cut in half length-ways.

Nymphs were placed at one of four temperatures regimes, each having a 14:10 hour light:dark regime: 16°C day temperature and 10°C night temperature; 16°C day temperature and 16°C night temperature; 14°C day temperature and 10°C night temperature; 14°C day temperature and 14°C night temperature. Twelve individuals were used in each temperature regime. Nymphs were inspected regularly to determine the beginning of the next developmental stage. Plants were inspected for the presence of exuviae (moulted exoskeleton) every two or three days to confirm the number of days taken to reach the next instar.

Results and discussion

Model development

Models have been developed that predict the phenology of tarsonemid mite and strawberry blossom weevil. These have been incorporated into the computer package containing models for strawberry diseases, WFT and capsid. These pest models use ASCII text files as input files (i.e. containing temperature data) since all weather data loggers should be able to produce ASCII text files. The programme provides a very flexible data format definition facility to define the exact data format for each specific data file. Users may run one or more of the four pest prediction models simultaneously through a screen form (Figure 1).

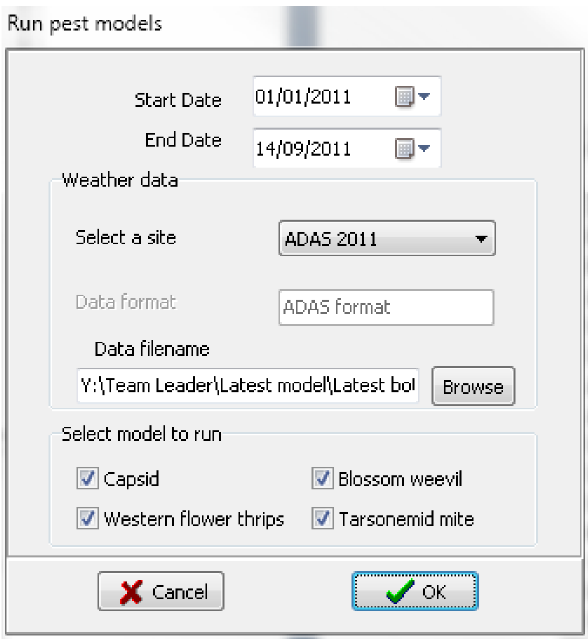

Figure 1. The ‘Run pest models’ form.

After running the model(s), the model predictions can be displayed (Figure 2 for tarsonemid mite, and Figure 3 for blossom weevil). These predictions are only used for illustration since in the real world temperature data should be recorded from January in the year in question.

In the coming year the field collated data on the field population dynamics (see the next section), especially the early spring development, will be used to further improve the capsid model. It is anticipated that at the end of this project, a validated capsid model should be ready for growers to use in practice.

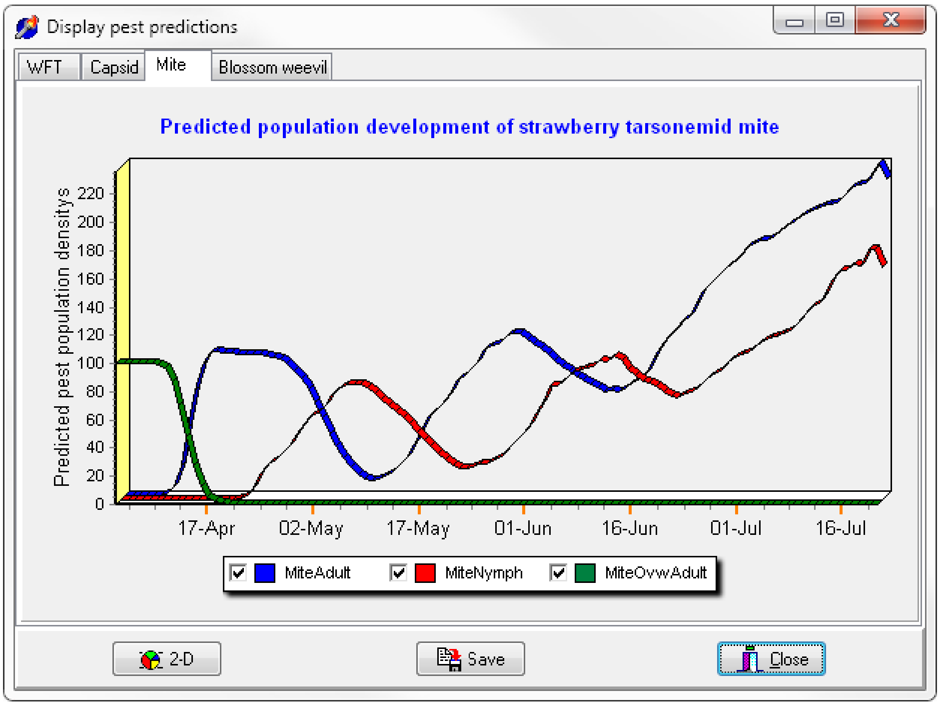

Figure 2. A screen shot of the model predictions for phenology of tarsonemid mites.

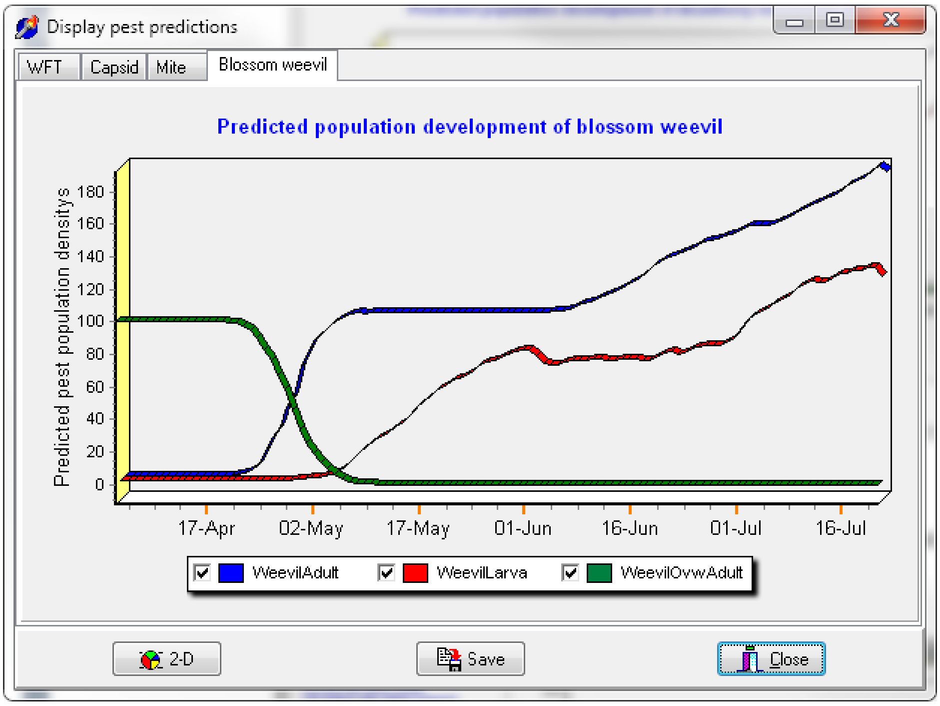

Figure 3. A screen shot of the model predictions for phenology of blossom weevils.

Experimental work with capsids

Field sampling - weeds

The species sampled were mainly fat hen (*Chenopodium album*), groundsel (*Senecio vulgaris*) and weeds such as *Matricaria* sp. For ease of comparison throughout the season, numbers of capsids caught have been normalised to the equivalent of 100 sweeps in Table 1.

Table 1. Numbers of *Lygus rugulipennis* nymphs (of each developmental stage) and adults caught in sweep samples on weed plots at East Malling Research in 2011. Numbers have been normalised to 100 sweeps.

Date	Nymphal stages					Adults
	1	2	3	4	5	
16 March	0	0	0	0	0	2.5
30 March	0	0	0	0	0	2.5
05 April	0	0	0	0	0	0
12 April	0	0	0	0	0	0
20 April	0	0	0	0	0	0
28 April	0	0	0	0	0	0
03 May	0	0	0	0	0	3
12 May	0	0	0	0	0	0
18-19 May	0.9	2.7	0	0	0	11.7
01 June	0	0.6	0.6	1.8	5.4	18
08-9 June	0	0	0.8	1.6	5.8	32
14 June	0	0	0	0	0	5

Date	Nymphal stages					Adults
	1	2	3	4	5	
16 March	0	0	0	0	0	2.5
30 March	0	0	0	0	0	2.5
05 April	0	0	0	0	0	0
12 April	0	0	0	0	0	0
20 April	0	0	0	0	0	0
28 April	0	0	0	0	0	0
03 May	0	0	0	0	0	3
12 May	0	0	0	0	0	0
29 June	0	0	0	0	1	4
09 July	0	0	1.3	0	2.5	8.8
13 July	0	1.4	1.2	0.9	0.5	7.3
19 July	0	1.3	3.8	3.8	1.3	10
28 July	3.8	7.5	13.8	8.8	3.8	1.3
03 August	40	30	17.5	7.5	17.5	25
11 August	3.5	6.3	11.2	27.3	52.5	10.5
01 September	0	1.6	4.2	2.5	15.8	23.2
04 September	0	0.8	2.1	1.5	6.2	27.9
14 September	0	0	0	0	5.5	91
22 September	0	0	1.3	2.5	10	67.5

Only adults were caught in the first samples taken on 16 March (Table 1), these being the overwintered adults. Both males and females were caught early in the season. Later in the season there was an approximate 50:50 ratio of males and females, as seen in samples in previous years. By the middle of May, second instar nymphs were present, indicating that eggs had been laid in April by the overwintered adults. The adults found at this time are likely to be overwintered adults. By early June mainly fifth instar nymphs and adults were caught. Second generation nymphs were found between mid-July to early-September. Relatively higher numbers of first, second and third instar nymphs were found from 13 July to 3 August, and relatively higher numbers of fourth and fifth instar nymphs were found in samples taken on 11 August to 4 September. There was a peak of first generation adults in July and of second generation adults in mid- to late- September. These peaks can be clearly seen in Figure 4.

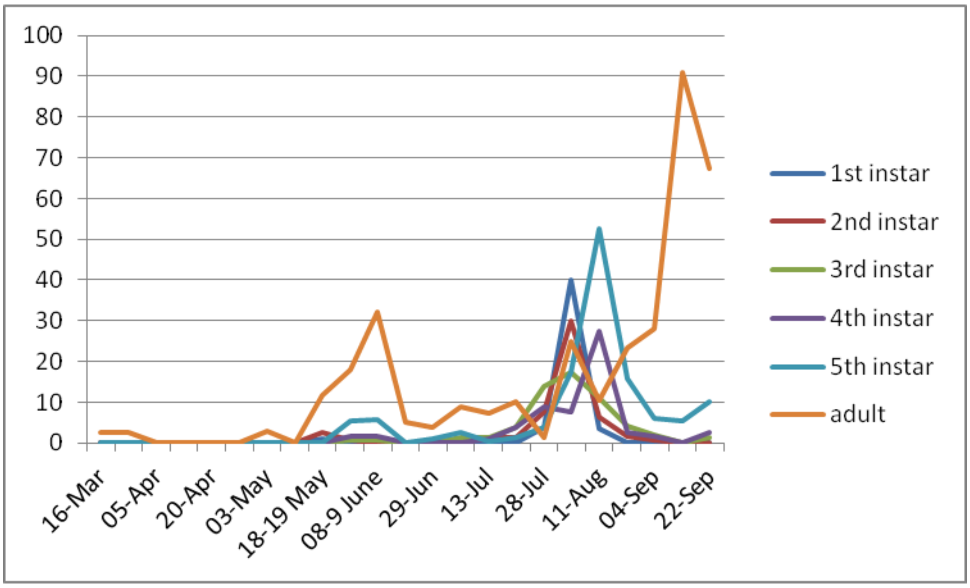

Figure 4. Development of *Lygus rugulipennis* populations on weeds in 2011

Field sampling – strawberries

L. rugulipennis (second and third instar) were found in tap samples on strawberries at EMR in the middle of May (Table 2), indicating that adults had laid eggs in the crop in late April. This is a similar timing to the presence of nymphs in weeds. This strawberry plot had weeds around it and the adults may have dispersed from these neighbouring weeds. Numbers caught were much lower in the strawberry than in the weed plots throughout the season. Higher numbers of nymphs were present in July and August and the nymphs of this generation were responsible for the damage seen to fruit in everbearer plantations. The pattern of development of the different life-stages from the field data collections will be used to validate the capsid prediction model. Temperature data (maximum and minimum) for the EMR site are shown in Figure 5.

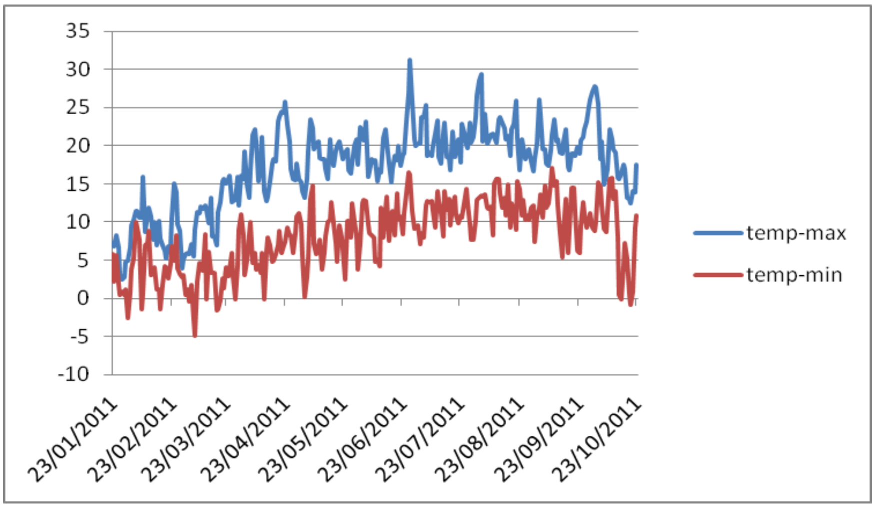

Figure 5. Maximum and minimum daily temperatures at EMR

Table 2. Numbers of *Lygus rugulipennis* nymphs (of each developmental stage) and adults caught in tap samples on a strawberry plot (DM 183) at East Malling Research in 2011

Date	Number of plants	Nymphal stages					Adults
		1	2	3	4	5	
20/04/2011	40	0	0	0	0	0	0
03/05/2011	50	0	0	0	0	0	0
12/05/2011	100	0	0	0	0	0	0
19/05/2011	100	0	1	1	0	0	2
08/06/2011	100	0	0	0	0	0	0
14/06/2011	100	0	0	1	0	0	1
29/06/2011	100	0	0	0	0	0	0
09/07/2011	100	1	0	0	0	0	1
13/07/2011	100	0	1	0	0	0	0
19/07/2011	100	0	1	2	0	0	1
28/07/2011	100	1	1	0	0	0	2
03/08/2011	100	1	6	1	2	1	0
11/08/2011	100	3	3	8	6	9	7
25/08/2011	100	0	0	0	0	5	3
05/09/2011	100	0	0	1	0	1	3
14/09/2011	100	0	0	0	0	0	2
30/09/2011	100	0	0	0	0	0	7

Tap samples of 50 strawberry plants at a commercial site (Table 3) showed that nymphs were not present there until 11 July. This is the timing normally seen in commercial (weed-free) plantations. Fifth instar nymphs were found by 28 July and adults by the 9 August. Mean temperature data for the commercial site are shown in Figure 6.

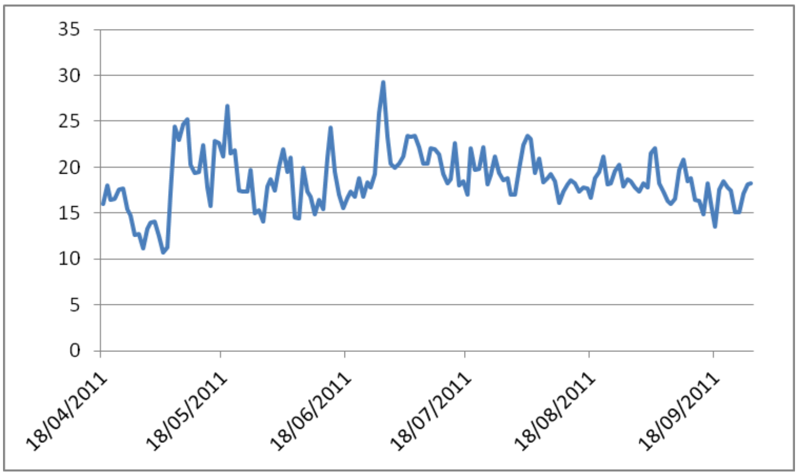

Figure 6. Mean daily temperature at the commercial strawberry site

Table 3. Numbers of *Lygus rugulipennis* nymphs (of each developmental stage) and adults caught in tap samples of 50 plants at a commercial strawberry planting in 2011

Date	Nymphal stages					Adults
	1	2	3	4	5	
27/04/2011	0	0	0	0	0	0
10/05/2011	0	0	0	0	0	0
02/06/2011	0	0	0	0	0	0
13/06/2011	0	0	0	0	0	0
30/06/2011	0	0	0	0	0	0
11/07/2011	2	0	0	0	0	0
28/07/2011	0	1	6	2	2	0
09/08/2011	0	0	1	2	2	2
24/08/2011	1	0	1	0	0	0

Field sampling - ovarian development

Two females were dissected to assess egg maturity. A female caught in weeds on 12 April had eight eggs which all looked well developed. A female caught two weeks before had less developed eggs, being smaller and looking ‘glassy’. It is likely that the female inspected at the end of March had not fully emerged from diapause and that the female examined on 12 April had developed to the stage where egg laying could begin. More individuals will be inspected in 2012.

Field sampling - pheromone traps

Pheromone traps in weed plots at EMR caught males when they were first put out in mid-March 2011. The last trap catch was on 14 September 2011. In the commercial strawberry plantation the first males were caught on 13 June, although with low numbers of one or two per trap (Figure 7). The peak *Lygus rugulipennis* catch for males was on 24 August.

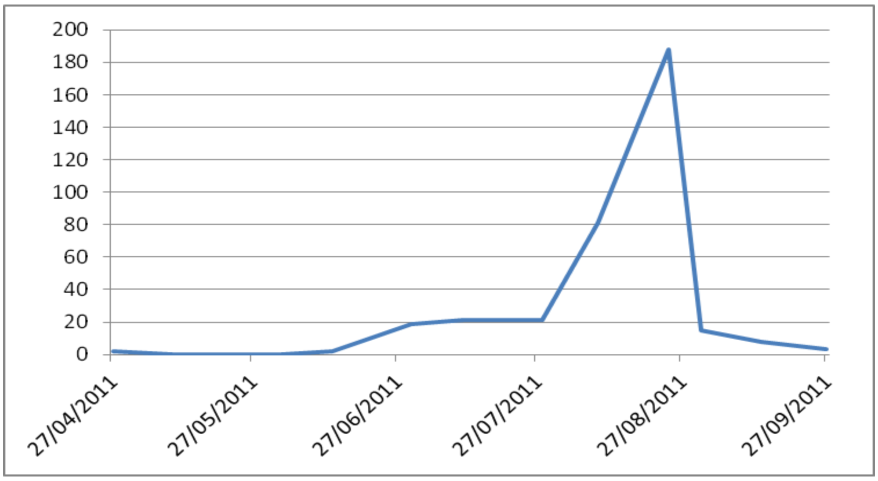

Figure 7. Mean numbers of *Lygus rugulipennis* males caught in four traps in a commercial strawberry plantation.

In 2012 no *L. rugulipennis* males were caught in traps in February at EMR. However all three traps caught males (four-seven per trap) on 1 March, and males were also caught in the subsequent sampling weeks in March, with up to 18 males per trap.

In addition to the field data collected by EMR researchers, capsid data has also been obtained from Clare Sampson of Keele University (Figure 8), who has kindly agreed for that the data she collected may be used to validate the capsid model.

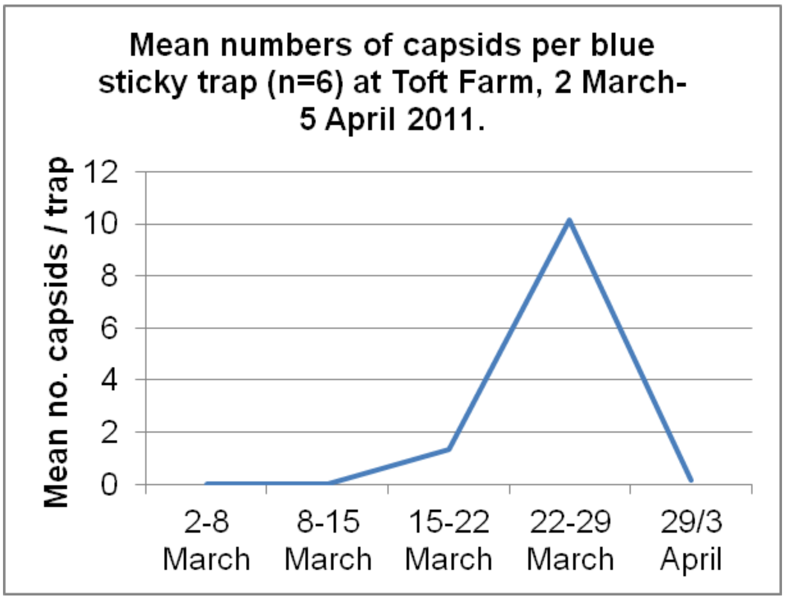

Figure 8. Number of the strawberry capsid adults caught in early 2011; data were kindly providedly by Clare Sampson of Keele University.

Laboratory development studies

The mean duration of each nymphal instar (days) at different temperature regimes is shown in Table 4. Individuals were at different developmental stages when they were collected and did not all complete development before dying. In addition, mortality is high in young nymphs. Therefore numbers of individuals contributing to the mean duration are given in parentheses. As expected, the nymphs that were held at a constant 16°C developed more quickly than those at the other temperature regimes. Total development time from the beginning of the second instar to adults was around 36 days at a constant 16°C compared to 46 days at 16°C:10°C; 51 at constant 14°C and 57 at 14°C:10°C. Rearing data obtained from other published papers normally give rates of development at constant temperature only. It is important to obtain fluctuating temperature data to enable predictions to be made about rates of development in the temperature region where development rates are not linear. These data will be used to modify the model.

Table 4. The mean duration of each developmental stage of *Lygus rugulipennis* in different temperature regimes with 14 hours light and 10 hours dark. Numbers contributing to the mean are shown in parentheses.

Temperature	Duration (days)			
	2nd instar	3rd instar	4th instar	5th instar
16°C day:16°C night	6.6 (3)	8.5 (4)	8.1 (8)	12.6 (10)
16°C day:10°C night	11.3 (3)	9.5 (6)	9.4 (8)	15.3 (10)
14°C day: 14°C night	13 (1)	10.3 (6)	11.6 (8)	15.7 (9)
14°C day: 10°C night	9.5 (4)	12.4 (7)	16.3 (10)	19.1 (10)

The developmental experiments were done when second generation nymphs were available. In 2012 more experiments will be done using first instar nymphs. Once these experiments have been completed in 2012, all the data will be analysed together to determine the development of the capsids under fluctuating conditions, and compared with model predictions of the development.

Conclusions

- Predictive models have been developed for tarsonemid mite and blossom weevil
- Experiments have been conducted to improve the capsid model, especially with respect to rates of development at fluctuating temperatures, capsid overwintering and the initiation of egg laying in the spring
- Data have been collected on pest population development under natural conditions in weeds and strawberry and these data will be used to evaluate and improve the model

Knowledge and technology transfer

This, and related work at EMR, has been discussed with leading growers on several occasions (including at Hort-LINK meetings) in 2011.

References

Easterbrook, M.A., Fitzgerald, J.D., Pinch, C., Tooley, J., & Xu, X.M. (2003) Development times and fecundity of three important arthropod pests of strawberry in the United Kingdom. *Annals of Applied Biology*, **143**, 325-331

