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:	Professor Xiangming Xu, Dr Jean Fitzgerald East Malling Research
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Location of project:	East Malling Research New Road, East Malling Kent, ME19 6BJ
Industry Representative:	Harriet Duncalfe
Date project commenced:	1 April 2010
Date project completed (or expected completion date):	31 March 2013

Disclaimer:

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.

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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31 March 2011

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31 March 2001

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Grower Summary

Headline

- A prediction model for the European tarnished plant bug *Lygus rugulipennis* has been developed which has been incorporated into a computer programme containing models for other strawberry diseases and pests.

Background and expected deliverables

Strawberries are very susceptible to many pests and diseases, most of which cannot currently be effectively controlled by non-pesticidal means. These include *Botrytis*, mildew, blackspot, European tarnished plant bug, 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; 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.

Diapausing adults of European tarnished plant bugs (capsids) overwinter on weeds or crop debris. The first generation of the pest develops on weeds, and adults from this generation migrate into strawberry where a second (and possibly a third) generation occurs. The migration 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 migrate 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 (HL 0191 – SF 94) is focusing on the development of a holistic Integrated Pest and Disease Management system for production of 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 this 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. In another Hort-Link project (HL 01107 – SF 120), a model for predicting western flower thrips development is also being developed.

There is only one key expected deliverable from this project:

1. A model forecasting capsid development on strawberry which is developed and ready for use by growers (together with models for other strawberry pests and diseases).

Summary of the project and main conclusions

A prediction model has been developed for strawberry capsid and incorporated into a computer programme that already contains models for strawberry grey mould, powdery mildew and western flower thrips. This model needs to be further improved, especially in relation to capsid overwintering and timing of first egg laying. Experiments have been initiated to obtain new biological data on capsid development in order to improve and validate the model. Regular sampling for the pest in weeds and strawberry fields has provided new information on the development of the pest within the crop related to temperature; these data will be used for validation of the model.

Financial benefits

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

Action points for growers

- No action points can be provided at this point since no firm conclusions have been drawn.

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*, mildew, blackspot, European tarnished plant bug, 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, all 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; 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 and mathematical models can be used to describe such temperature-developmental-rate relationships. These relationships will be different for different insect and mite species.

A current Hort-Link project is focusing on the development of a holistic integrated pest and disease management system for production of 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 this 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). 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, we are also developing a model that predicts population development of western flower thrips (WFT). This model has also been incorporated with the disease models.

In the present project, we aim to develop models for other key strawberry pests, focusing on European tarnished plant bugs (capsids). In addition to collecting data on capsid development in relation to temperatures for developing and validating the model, we also need to understand the overwintering behaviour of this pest. Diapausing adults of European tarnished plant bugs overwinter on weeds or crop debris. The first generation of the pest develops on weeds, and adults from this generation migrate into strawberry where a second (and possibly a third) generation occurs. The migration 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 migrate 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 first year of this project was divided into two parts: (1) developing predictive models, and (2) developing experimental protocols (and initiating the experiments) to obtain further data for developing and validating the model.

Materials and methods

<u>Development of prediction models</u>

We have developed a predictive model for capsids which simulates population development from overwintering adults onwards. The model uses either hourly or daily temperature data to estimate pest development. This initial model was developed on the basis of data collected recently at EMR (Easterbrook *et al.*, 2003). Currently we have made several key assumptions relating to capsid overwintering:

(1) only adults can overwinter

(2) these overwintering adults are not mature for sexual reproduction

(3) the overwintered adults become sexually active only in the spring after breaking diapause

(4) breaking diapause is only dependent on temperature (precise thresholds are unknown)

Some of the above assumptions will be tested using historical data at East Malling Research, published work and data to be obtained in Years 2 and 3. The model always starts from January of the year in question and assumes there are 100 overwintering adults.

Experimental work

Field sampling

Weeds: Sweep samples were taken on weed plots between 30 April and 22 November 2010. 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. Numbers of sweeps depended on numbers of Lygus present so if there were none or hardly any present more time was spent looking for them to get an idea of when they first became active, hence higher numbers of sweeps. So in April when Lygus were likely to be present in low numbers, with mostly overwintered adults and no nymphs, higher numbers of sweeps were made and in July when large populations had developed numbers of sweeps were lower. The numbers of *Lygus rugulipennis* nymphs (recorded to developmental stage) and adults caught in sweep samples were identified and recorded in the laboratory. Total numbers recorded from each sample date were calculated.

Strawberry: Tap samples were taken on an everbearer strawberry planting (DM 183) at EMR between June and November; the variety was Evie 2. The strawberry plants were tapped over a white circular tray and the numbers of of *Lygus rugulipennis* nymphs (recorded to developmental stage) and adults caught were recorded in the field.

Laboratory development studies

A protocol was developed to assess rates of development of *L. rugulipennis* from egg to adult on plant material in the laboratory, and in initial experiments the development of *Lygus rugulipennis* nymphs was monitored until adulthood under a variable temperature regime. Adult females were introduced to a cage containing groundsel plants (*Senecio vulgaris*) and left to lay eggs. The plants were then monitored daily for the presence of nymphs by tapping them over a white tray. One day old nymphs were used in the experiments. These nymphs were held individually in small Perspex boxes (16 x 10 x 8 cm approx). Each box contained a shoot of groundsel taken from glasshouse reared plants in a polypot of water, with the stem going into the water through a hole in the lid. Any gaps between the stem and the pot lid were plugged using absorbent towelling to prevent the nymph from drowning. Nymphs were placed in an incubator at 15°C day temperature with 14 hours light and 10°C night temperature with 10 hours dark. Nymphs were inspected and measured regularly to determine the beginning of each developmental stage. Plants were also inspected for the presence of exuviae (moulted exoskeleton) every 2 or 3 days to determine the number of days to reach each instar.

Results and discussion

<u>Model development</u>

A prediction model has been developed for capsid and incorporated into the computer package developed for strawberry diseases and WFT (Figure 1).

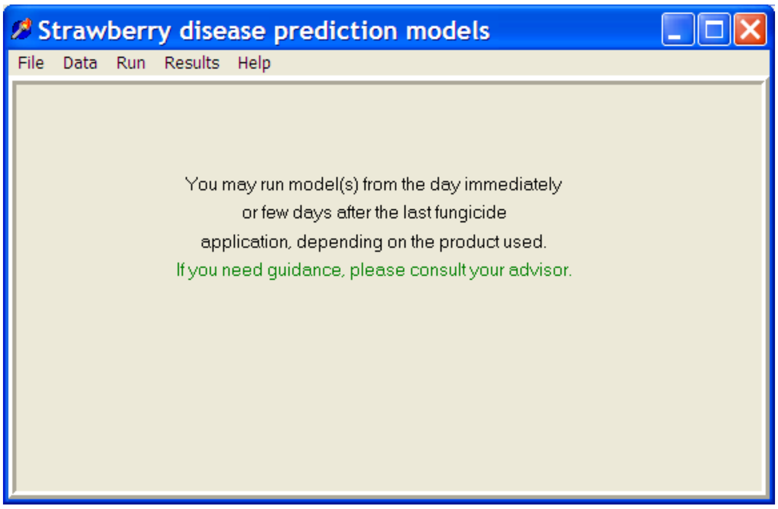

Figure 1. A screen shot of the main window of the strawberry prediction system

This model uses ASCII text files as input files (i.e. containing temperature data). 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 WFT and capsid models either separately or simultaneously through a screen form (Figure 2).

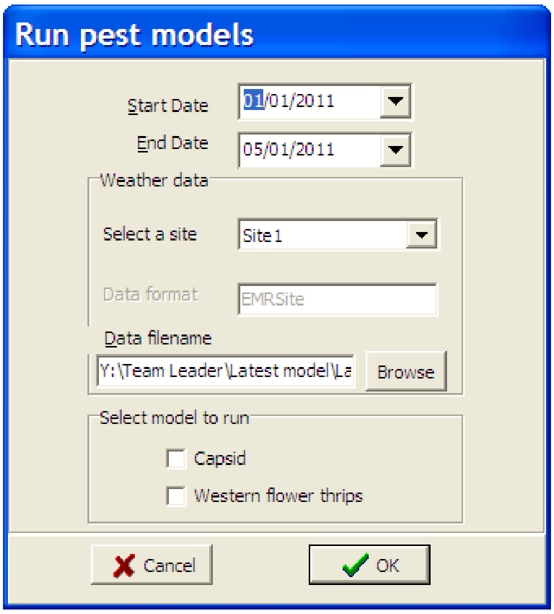

Figure 2. The ‘Run the model’ form

After running the model(s), the model predictions can be displayed (Figure 3); this prediction is only used for illustration since in the real world temperature data should be recorded from January in the year in question.

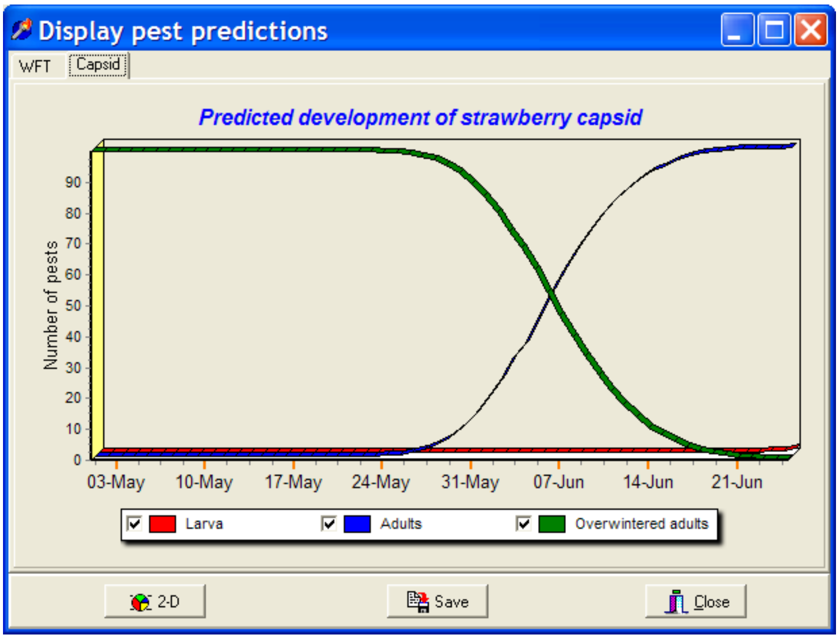

Figure 3. A screen shot of the model predictions for capsids

In addition, we have also implemented a flexible computer algorithm for calculating degree-days (Figure 4).

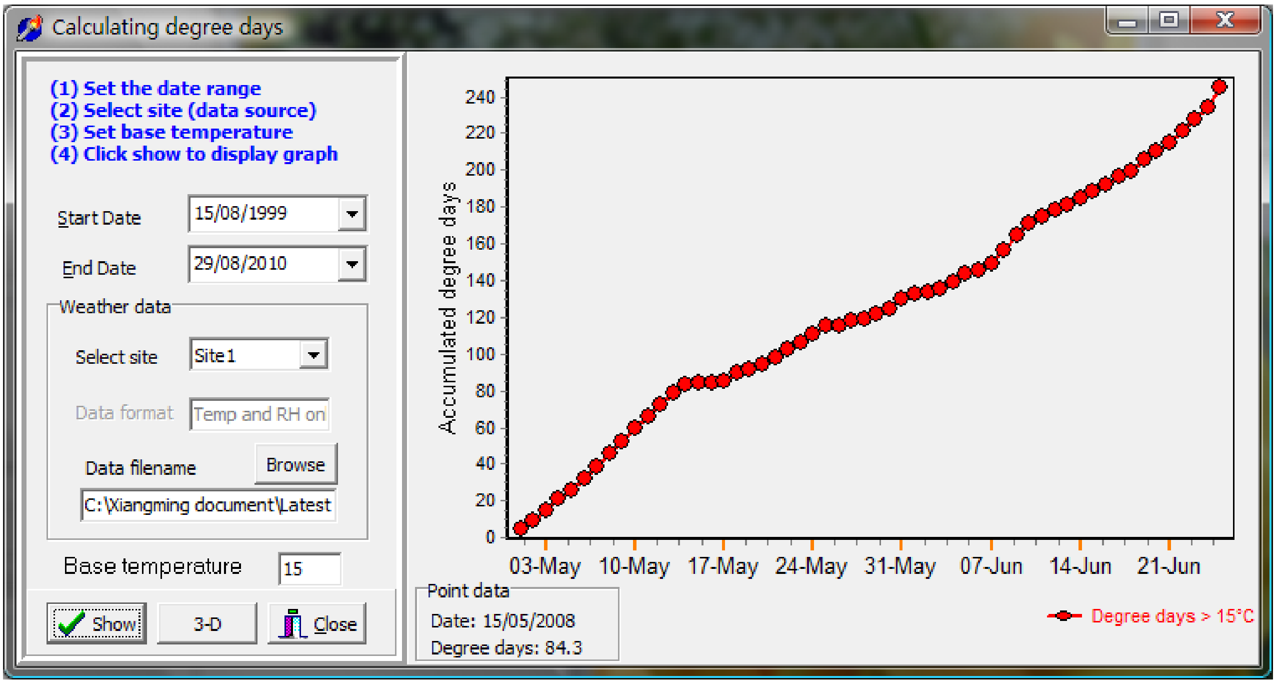

Figure 4. The 'Calculate degree-days' form

This degree-day tool enables users to define any new models based on degree days and can be a powerful tool to test new models very quickly, which may be particularly useful for consultants.

<u>Experimental work</u>

Field sampling

Weeds: The species sampled were mainly fathen (*Chenopodium album*), groundsel (*Senecio vulgaris*) or a mixture of cornflower (*Centaurea cyanus*), corn chamomile (*Chrysanthemum segetum*) and corn marigold (*Anthemis arvensis*); this mixture was sown for a different experiment). Total number of sweeps taken per date ranged from 29 (on 13 July) to 240 (on 30 April) depending on *L. rugulipennis* abundance; most dates had 100 or more sweeps. For ease of comparison throughout the season, numbers have been normalised to 100 sweeps in Table 1. Only adults were caught in the first samples taken on 30 April (Table 1), these being the overwintered adults. By 24 May, 3rd instar nymphs were present indicating that eggs had probably been laid in April by the overwintered adults.

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 2010; samples normalised to 100 sweeps

Date	Nymphal stages					Adults
	1	2	3	4	5	
30 April	0	0	0	0	0	6
14 May	0	0	0	0	0	0
24 May	1	2	3	0	0	7
3 June	0	0	0	0	0	7
16 June	0	0	1	3	2	5
23 June	0	2	1	0	2	14
5 July	0	0	0	0	0	4
7 July	0	0	0	0	0	9
13 July	0	0	0	0	0	79
20 July	0	1	1	0	1	19
28 July	1	4	6	4	3	16
3 August	9	18	15	11	3	23
11 August	38	48	53	22	5	28
18 August	60	61	68	66	26	19
23 September	0	1	8	28	261	629
30 September	0	0	1	0	21	804
7 October	0	0	0	1	13	510
21 October	0	0	0	0	0	129
28 October	0	0	0	0	0	70
11 November	0	0	0	0	0	16
22 November	0	0	0	0	0	42

Nymphs were found in low numbers in samples until 5 July; this is likely to be the end of the first generation nymphs, with a peak of adults of this first generation caught on 13 July. Nymphs were again found in low numbers at the end of July, with relatively higher numbers of 1, 2 and 3 stages in the samples on 3, 11 and 18 August, and relatively higher numbers of 4 and 5 stages in samples taken on 23 September, with a subsequent peak of second generation adults on 30 September. Adults were still active into November.

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 2010; samples normalised to 80 taps

Date	Nymphal stages					Adults
	1	**2**	**3**	**4**	**5**	
7 June	0	0	0	0	0	0
23 June	0	0	0	0	0	0
7 July	0	0	0	0	0	0
20 July	6	2	0	0	0	1
28 July	0	4	0	0	0	12
11 August	14	10	14	6	2	14
18 August	3	6	15	4	3	4
28 August	8	8	8	8	0	8
2 September	4	8	12	9	7	4
9 September	1	2	8	10	4	6
23 September	0	1	3	5	20	9
24 September	0	2	0	4	0	10
30 September	0	3	5	2	6	11
7 October	0	1	0	1	0	4
21 October	0	0	0	0	1	5
28 October	0	0	0	2	1	24
10 November	0	0	0	0	0	2
24 November	0	0	0	0	0	3

No *L. rugulipennis* were found in tap samples on strawberries until late July. First and second stage *L. rugulipennis* nymphs were caught in July (Table 2), indicating that adults had laid eggs in the crop earlier in July. Nymphs present in July and August are responsible for the damage seen to fruit in everbearer plantations. The pattern of development of the different lifestages from the files data collection will be used to validate the prediction model. Temperature data are also available for the EMR site. Further sampling will be carried out in 2011 on both weeds and strawberry.

Laboratory development studies

The mean body length of *Lygus rugulipennis*, from the head to the base of the abdomen (x10 magnification) at the first observation after moulting is shown in Table 3 and time to develop to each stage at 15°C day temperature with 14 hours light and 10°C night temperature with 10 hours dark in Table 4. The number of insects followed through their development is shown in both tables. Although initially 16 individuals were set up there was a high mortality rate during development, hence only the nymphs that developed to at least 5th instar have been included in the results.

Table 3. Relative body size of different developmental stages of *L. rugulipennis* nymphs after moulting

Lygus stage	Number recorded	Mean body length at moult (relative units)
2nd	5	1.35
3rd	5	1.72
4th	5	2.3
5th	5	3.08
Adult	3	5.17

Table 4. The mean number of days taken for development of each stage of *Lygus rugulipennis* at 15°C day and 10°C night temperature with 14 hours light and 10 hours dark

Lygus stage	Number recorded	Days
1st	5	12.1
2nd	5	10.6
3rd	5	9.6
4th	5	11.4
5th	3	15.8
Total number of days from 1st instar to adult		59.5

These experiments have given us new information on rates of development at low fluctuating temperatures. In 2011 more individuals will be reared under experimental conditions used in 2010 and in other fluctuating and constant temperature regimes to obtain more information on development of this pest to improve the model. In addition experiments will be set up to determine when overwintered adults begin to lay eggs; this is necessary to get a biofix point i.e. the appropriate time at which to begin the population model.

Conclusions

- We have developed a predictive model for capsids
- More data are needed to improve the model, especially with respect to capsid overwintering and the initiation of egg laying
- Protocols have been developed and new experiments and regular sampling have been initiated to obtain data for improving and validating the model

Knowledge and Technology Transfer

We have discussed this and related work at EMR with leading growers on several occasions (including at Hort-Link meetings) in 2010.

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