Project Title	Tunnel-grown everbearer strawberry: biology and integrated control of western flower thrips
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Project leaders:	Jude Bennison, ADAS Dr Jean Fitzgerald, EMR
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The results and conclusions in this report are based on a series of experiments 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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Grower Summary

Headline

- Western flower thrips (WFT) was confirmed on 44% of farms surveyed.
- In experiments in Kent the majority of WFT were found to pupate in the soil directly under the plants and under the polythene of the raised beds. The pest successfully overwintered in an everbearer field in low numbers.

Background and expected deliverables

Over the past three years significant economic losses have occurred in some everbearer strawberry crops due to thrips damage. Several different thrips species can infest strawberry crops, but western flower thrips (WFT) is becoming more prevalent and is thought to be responsible for the main thrips damage symptoms (fruit russeting). Identification of thrips is a specialist job and many strawberry growers are unaware of which thrips species are present on their farms.

Until recently, growers have used the pyrethroid Talstar/Starion (bifenthrin) for control of thrips and some other strawberry pests. However, WFT is resistant to this and many other insecticides. Some glasshouse strawberry growers are successfully using Integrated Pest Management (IPM) programmes with very limited pesticide use, achieving biological control of thrips primarily with the predatory mite *Amblyseius cucumeris*. However, biological control of thrips in outdoor and tunnel-grown everbearers has proved unreliable and many growers still rely on pesticides.

In June 2005, a specific off-label approval (SOLA) was secured for the use of Tracer (spinosad) on protected strawberry. Tracer is currently the most effective pesticide against WFT, but unlike Talstar/Starion, it is compatible with most biological control agents. However, resistance has already been confirmed in WFT populations in other countries. It is therefore essential that Tracer is used within an integrated strategy rather than as the only means of control.

The biology of WFT in strawberry crops is not fully understood. This project aims to provide key information on WFT biology and behaviour in everbearer crops, including where it pupates in the crop, and whether (and where) it overwinters. This project also aims to identify how widespread WFT is on everbearer crops in England and Scotland, and to design improved integrated control strategies.

Results of the project will enable growers to target the pest more effectively with biological control agents, within improved, sustainable integrated control strategies.

The expected deliverables in year 1 were:

1. Identify the extent of WFT occurrence in everbearer strawberry on a wide geographical spread of strawberry farms in England and Scotland and identify factors affecting thrips incidence and success of integrated control strategies. (This work was undertaken by ADAS).

2. Determine the pupation sites of WFT during the summer period in an everbearer strawberry crop grown under poly tunnels. (This work was undertaken by EMR).

3. Determine whether WFT overwinter within an everbearer strawberry crop and if so identify when they emerge and become active in the following season. (This work was undertaken by EMR).

Summary of the project and main conclusions

Objective 1: occurrence of WFT and case studies (ADAS)

Flower samples were collected or received from growers or consultants, from 18 strawberry farms (on a wide geographical spread in England and Scotland), between 6 June and 11

October 2006. A total of 47 thrips samples were examined and the presence or absence of WFT was determined. In addition, those growers or consultants who provided samples were asked to complete a short questionnaire. They were asked to provide variety name, planting date and age of bed, along with brief details on how thrips and other pests and diseases were being managed.

- WFT was confirmed on 8 of the 18 farms sampled; one of these was on a non-everbearer crop under glass and the others were all field-grown everbearers. Most were tunnelled at the time flowers were sampled.

- WFT was confirmed as being widely spread throughout England.

- WFT was not found in samples from Scotland in 2006 but this does not confirm that they are absent. WFT were found in consultancy samples sent to ADAS from Scotland in 2005.

- Results suggest that WFT is more of a problem in fields with a history of WFT and where plants or beds are retained from one year to the next. However, WFT was also confirmed on a few new plantings and on sterilised beds. Case study visits were made on three farms where WFT had been confirmed and where biological control methods had been used for thrips. This was done to obtain information on factors affecting WFT incidence and integrated control. The farms were located in Norfolk, Kent and Herefordshire (case studies 1, 2 and 3 respectively).

- On the Norfolk site, *Amblyseius cucumeris* (*A. cucumeris*) provided good control of WFT in a glasshouse crop. Similar results were achieved in a glasshouse crop at a survey site in Yorkshire. WFT had been a severe problem at both sites in 2005, when pesticides had given poor control (before Tracer was available for use on strawberry). Other pests were adequately controlled in the glasshouses, either by biological control agents or by IPM-compatible pesticides.

- Where pesticides had been used for control of either thrips or other pests in the field, or in Spanish tunnel-grown everbearer crops, *A. cucumeris* gave unreliable thrips control at some survey sites.

- However, WFT was not present at all sites using *A. cucumeris*.

- *A. cucumeris* were mainly introduced on everbearer crops as single releases, at the rate used for tarsonemid mite control. On most sites, the predators are likely to have been released too late and at inadequate dose rates and frequency for thrips control.

- Pesticides used for thrips and other pests and diseases on most everbearer crops would have had adverse effects on *A. cucumeris*.

Objective 2: pupation sites of WFT during the summer (EMR)

Due to the high summer temperatures in 2006, the plants that were to be used for this experiment turned thermo-dormant and stopped flowering in July. Several attempts were made to encourage the plants to recommence flowering but these were not successful and very few flower clusters developed. Therefore, alternative experiments were set up in the field and glasshouse to attempt to identify WFT pupation sites.

Small potted flowering strawberry plants were planted in raised beds in the field, covered with agricultural fleece and infested with WFT. Subsequently samples were collected from different positions inside each fleece cage to assess numbers of WFT pupating in each position; thrips adults emerging from pupae that had been in the samples were caught on sticky traps.

- A total of 51 adult WFT were caught in this experiment; 49% of these emerged from soil taken from under the plant, 37% from soil under the polythene, 12% from the straw in the alleys and 2% from the soil under the straw layer.

Three artificial raised strawberry beds were created in a glasshouse compartment at EMR. WFT were released on the plants and samples collected and assessed as above.

- A total of 110 thrips were caught on the yellow sticky traps; 60% of these emerged from soil taken from under the plants, 15% from soil under the polythene, 12% from the straw and 7% from the soil under the straw.

Emergence traps were used *in situ* on the artificial raised beds to monitor thrips emergence.

- A total of 21 thrips were caught in these emergence traps; 71% of these emerged from soil under the plant, and 9% from each of soil under polythene, straw and soil under straw.

Samples were taken to assess emergence of thrips adults at the grower site in Kent that was heavily infested with WFT (case study 2). *In situ* emergence traps were also set up at this site.

- In the samples that were returned to the laboratory, only 15 thrips were caught on the sticky traps; 40% of these emerged from soil under the plant and the remaining 60% from the straw samples but these numbers were too low to enable conclusions to be made about pupation sites.

- In the *in situ* emergence trapping, 259 thrips were caught in the traps; 60% of thrips emerged from soil from the planting hole, 27% from elsewhere in the grow bag, 1% from the straw, 1% from soil under the straw and 12% from under the Mypex. However, at the time the samples were collected much of the soil under the straw was flooded and the straw was very wet, and this may have affected thrips survival.

The low numbers of flowers and small populations of WFT that established in the field at EMR, the artificial nature of the glasshouse experiment and the unconventional growing system at the farm in Kent constrain the confidence with which individual results can be interpreted. However, taken together all the experiments indicated that the greatest number of WFT pupated in the soil directly under the plant and in the soil close to the plants within the raised beds or grow bags. Generally, low numbers of emerging adults were found in samples of straw or soil under the straw in the alleys. Very few pupae were recorded on plant material during these and other (Defra funded) experiments with WFT on strawberry undertaken at EMR. This pattern of dispersal for pupation will have a bearing on the possibilities for biocontrol strategies against WFT pupae.

Objective 3: do WFT overwinter in everbearer strawberry fields, and if so, when do they emerge? (EMR & ADAS).

Cages covered with horticultural fleece were used at EMR to cover the experimental plants and the adjacent alley on 27 September 2006, and at least 200 WFT (mixed stages) were released onto each plant. Cages were removed on 22 November 2006, which ensured that the natural microclimate around the plants was not altered during the winter months. Cages were replaced in the week commencing 26 March 2007. In early March, yellow and blue sticky traps were hung on stakes in the plantation above the plants and close to areas where WFT had been released in 2006. Traps were replaced on 8, 16 and 27 March and on 12 April.

- No thrips were found on the sticky traps collected on 8 March.
- On traps collected on 16 March, 15 thrips were recorded, of which two were confirmed as WFT.
- On 12 April 64 thrips were found on the traps; 32 of these were removed for inspection and 2 were identified as WFT.
- On 4 May a subsample of 32 thrips were removed from traps and of these 2 were identified as WFT.
- These results confirm that WFT can overwinter in the field in the south east of

England, and the earliest emergence date was between 8 and 16 March.

- A Delta T® data logger with multiple sensors was used at EMR to record temperatures in positions within the crop where WFT might be expected to overwinter. Temperatures were recorded every hour from 21 November 2006 to 31 May 2007.
- The lowest temperature recorded (-1.4ºC) was from under the soil in the planting hole on 7 February 2007; lowest temperatures were also recorded on this date under the polythene mulch and in the plant crown.

- The lowest temperature under the straw in the alleys was 2.3ºC, recorded on 8 February.
- There were always positions in the crop that were above freezing and could provide refuges for overwintering insects. However, this was a relatively mild winter and the effect of colder winter conditions on the overwintering ability of WFT needs to be tested.

Tinytalk® dataloggers were placed by ADAS in similar locations to those used at EMR, in a commercial everbearer field in Herefordshire. The field was the one used in the case study (site 3) undertaken for Objective 1, and WFT had been confirmed in the field on sequential dates during the 2006 season. The strawberry beds and plants were kept over the winter of 2006 and used for cropping in 2007. Temperatures were recorded every hour from 8 November 2006 until 12 May 2007. As in Kent, the winter was very mild and only one sub zero temperature was recorded, on 7 February (-0.1ºC, under the polythene). WFT adults and larvae were identified by ADAS in the Herefordshire crop on 3 May, when the experiment in Objective 4 was set up. WFT adults must have been active in the crop before that date, as they were already breeding in the first strawberry flowers. The results suggest that WFT had probably overwintered on site.

Objective 4: Using knowledge gained from objectives 1-3, design and test integrated control strategies for WFT (EMR & ADAS).

After consideration of the information gained in earlier project objectives, and following discussions with biological control suppliers, growers and the HDC technical manager Lindrea Latham, it was decided to test the effectiveness of predatory mites against WFT in the 2007 experiments.

ADAS set up an experiment on 3 May 2007, on a commercial everbearer crop (cv. Everest) in Herefordshire, in the same field used for monitoring temperatures in Objective 3. The field had a history of WFT. The replicated treatments were three consecutive introductions of the predatory mite *Amblyseius cucumeris*, used at two release rates, compared with an untreated control.

EMR set up an experiment in the week commencing 30 July in an everbearerstrawberry plantation planted for this purpose on 3 May 2007. The plants were de-blossomed and de-runnered on 15 June and had an application of pyrethrum on 10 July to remove predators and any thrips species other than WFT. There were no flowers on the plants on 3 July but they were flowering well by the end of July.

In the ADAS and EMR experiments sequential assessments are being made of numbers of thrips and predators in flowers, the proportion of WFT in the thrips population, the species of predatory mites present and any thrips damage to fruit. As the experiments are still in progress at the time of writing this report, the results will be presented and discussed in the project annual report in 2008. Biological control strategies to be considered for the experiments in 2008 will be decided after assessing the results from 2007.

Main conclusions

- Western flower thrips (WFT) was confirmed on eight of 18 strawberry farms sampled in England and Scotland during 2006.
- WFT was more of a problem on farms or fields with a history of the pest, and on second year plants and/or beds.
- Use of *Amblyseius cucumeris* by growers included in the survey gave good control of WFT in glasshouse crops, but often gave inadequate control on everbearer crops grown outdoors and under Spanish tunnels.

- Most WFT were found to pupate in the soil directly under strawberry plants and under the polythene of the raised bed.
- WFT overwintered in very low numbers in an experimental strawberry planting at EMR.
- Temperature recording at different positions within the planting at EMR and Herefordshire showed that there were always areas that remained above 0ºC that may have acted as refuges for the pest.
- WFT were found reproducing in the crop in Herefordshire in early May indicating that they had overwintered on site.
- Increased grower awareness of WFT and new knowledge about WFT biology and behaviour in everbearer crops will enable improved integrated control strategies to be designed and tested later in this project.

Financial benefits

The results of the project have already increased grower awareness of WFT as a pest of everbearer strawberry. However, it is too early in the project to quantify any financial benefits of the research.

Action points for growers

- Ensure that thrips populations on each everbearer strawberry field are identified each season, to 'map' incidence of WFT on the farm.
- Manage integrated control programmes carefully, using pesticides only if needed, and selecting those safest to any biological control agents being used.
- Follow Resistance Management Guidelines for Tracer, taking care not to exceed the maximum of three applications per crop per year.
- In the 2008 season, if WFT has been present in 2007, and if planning to use *Amblyseius cucumeris* for thrips control, do not delay release until the first thrips are seen and do not rely on the release rates recommended for tarsonemid control. Discuss your IPM programme with your biological control supplier and consultant well in advance.

Science Section

Introduction

Everbearer strawberries provide 50% of total strawberry yield on a typical farm producing for supermarkets. Over the last three years there have been significant crop losses due to thrips damage (such as fruit russeting) on some farms. Main season varieties grown under glass are also at risk.

From six sites sampled by East Malling Research (EMR) in 2003 (SF 60), *Thrips major* (rose or rubus thrips), and *T. tabaci* (onion thrips) were most abundant, with western flower thrips (WFT), *Frankliniella occidentalis*, found only at one site (Fitzgerald, 2004). In July 2005, ADAS confirmed WFT to be present at each of four sites in England and Scotland (Bennison, unpublished data). At one site, WFT was the only species found and at the remaining sites it was present with a mixture of other species, including *T. major*, *T. fuscipennis* (also known as rose thrips), *T. tabaci* and *T. vulgatissimus* (no common name). WFT appears to be becoming more prevalent on everbearer strawberries grown under plastic polytunnel protection; one reason for this could be the higher temperatures found under protection.

Some UK growers of protected strawberry are using Integrated Pest Management (IPM) with very limited pesticide use, basing biological control of thrips mainly on the predatory mite *Neoseiulus (Amblyseius) cucumeris*, sometimes supplemented with spot releases of the predatory mite *Hypoaspis* sp. and/or the predatory bug *Orius* sp. This strategy is successful under glass but is less reliable in tunnel-grown strawberries, although naturally-occurring *Orius* spp. can give useful control if allowed to establish. Pesticides used against other pests e.g. capsids and against diseases can interrupt biological control of thrips in tunnel-grown crops.

Many other growers are reliant on pesticides alone for thrips control. Until recently growers have used the pyrethroid bifenthrin (Talstar/Starion) against thrips and some other strawberry pests. This pesticide kills all thrips species except WFT (which is resistant to pyrethroids and many other pesticides); this could contribute to the predominance of WFT at some sites. Talstar is also lethal to all released and naturally-occurring beneficial invertebrates e.g. predatory mites (*Amblyseius* spp.) and predatory bugs (*Orius* spp.). Thrips surviving Talstar will therefore not be kept in check by natural enemies.

In June 2005, Tracer (spinosad) was given specific off-label approval (SOLA) for use on protected strawberry. Tracer was shown to be effective against WFT in bioassays and a field experiment undertaken by EMR in SF 60 (Fitzgerald, 2004). Although Tracer is currently the most effective pesticide against WFT, resistance has already been documented in other countries (Herron & James, 2005; Loughner *et al.*, 2005). As part of a resistance management strategy in the UK, Tracer is limited to three applications per structure per year. Therefore it is essential that it is used within an integrated strategy rather than as the only means of control.

The biology of WFT in strawberry crops is not fully understood. This includes uncertainty about the main source of the pest, which could include brought-in infested strawberry plants, wild or other cultivated host plants from which adults migrate into the strawberry crop, or overwintering sites in the field. There is evidence that WFT may survive mild winters by sheltering in soil or plant debris (McDonald *et al.*, 1997). Some strawberry growers have observed higher WFT numbers in the second year pick of everbearers, indicating that WFT might overwinter on site and present a potential threat in the following season.

Another key aspect of WFT biology is where it pupates in the host crop. In research in a Defra-funded project (HH3102TPC), Bennison (2006) confirmed that on chrysanthemum and cucumber, most WFT pupate in the soil or substrate beneath the plants (Bennison *et al.*, 2004). Confirmation of the pupation site of WFT within strawberry plantings (e.g. on the plant, in the soil around the plant or in the soil or leaf litter in the alleys) could improve control methods by enabling targeted application of certain biocontrol agents to these areas.

Some biocontrol agents, such as the predatory mites *Hypoaspis* spp. and the entomopathogenic nematode, *Steinernema feltiae* ('Nemasys F'), will reach WFT larvae and pupae in the soil, whereas pesticides will not. In a review of potential biocontrol strategies in strawberry and raspberry by EMR (SF 66), the possibility of using a soil-dwelling predatory mite, *Hypoaspis miles*, together with the already widely used plant-inhabiting mite *Neoseiulus (Amblyseius) cucumeris* to enhance biocontrol of thrips in strawberry was highlighted (Fitzgerald *et al.*, 2005). Both *Hypoaspis miles* and *H. aculeifer* were shown in Defra-funded research project (HH3102TPC) to feed on late second stage WFT larvae which drop to the ground to pupate, and also on the pupal stages (Bennison *et al.*, 2002), whereas *A. cucumeris* feed only on the first stage larvae on the plants. 'Nemasys F' is currently successfully being used by some chrysanthemum growers to control WFT. The nematodes are compatible with most pesticides and biological control agents. Research in Defra project HH3102TPC confirmed that foliar sprays of 'Nemasys F' can reduce WFT populations on chrysanthemums, and indicated that the main life stages killed may be those in the soil, as even when applied as foliar sprays, nematodes do reach the growing medium (Bennison, 2006). EMR results from SF 60 (et al.,, 2004) and trials done by Becker Underwood Ltd (the supplier of 'Nemasys F') have shown that foliar sprays of the nematodes can give some control of WFT on strawberry. Growers need to know how the nematodes might be used successfully and economically for WFT control on strawberry.

Overall aim of project

The overall objective is to improve integrated control of WFT on tunnel-grown everbearer strawberry. This will be achieved by determining key aspects of WFT biology and behaviour on strawberry to enable integrated control strategies to be more effectively and economically targeted against the pest, and by testing different combinations of biological control agents within an integrated control strategy.

Objective 1

Identify the extent of WFT occurrence on everbearer strawberry on a range of geographically spread strawberry farms in England and Scotland and identify factors affecting thrips incidence and integrated control (ADAS).

Materials and Methods

Flower samples were collected or received from growers or consultants, from 18 geographically spread strawberry farms in England and Scotland, between 6 June and 11 October 2006. Most of these samples were from everbearer strawberry crops, although samples from glasshouse crops at two farms were included. More than one field was sampled on some farms, and some fields were re-sampled on several occasions through the season. A total of 47 thrips samples were examined. Growers or consultants were supplied with collection tubes and padded envelopes, and asked to send 50 flowers from an everbearer crop with a thrips infestation.

Thrips were removed from the flower samples and presence or absence of WFT was determined in the laboratory. Any other thrips species present were only identified to genus level, to distinguish them from WFT. In addition, a short questionnaire was discussed with, or sent to the growers or consultants providing the samples. Growers were asked to confirm variety, planting date and age of bed, and to give brief details on how thrips were currently being managed, and what pesticides had been applied for other pests and diseases.

Case studies were undertaken through site visits to three strawberry farms where WFT had been confirmed and where biological control for thrips was being used, in order to obtain information on factors affecting WFT incidence and the success of the biological control strategies.

Results and Discussion –WFT occurrence

A summary of the results is given in Table 1.

- WFT was confirmed as present on 8 of the 18 farms sampled; one of these was on a non-everbearer crop under glass (site 6), the others were all field-grown everbearers (most were tunnelled at the time flowers were sampled).
- On some farms, more than one field was sampled. WFT was confirmed on a total of 10 everbearer fields.
- Other thrips species in the flower samples were not all identified to species, but included *Thrips* spp., *Limothrips* spp. and *Frankliniella intonsa* (the latter was identified to species to distinguish it from WFT, *Frankliniella occidentalis*).
- WFT was confirmed in samples from the following counties:

  Herefordshire (2 out of 2 farms)

  Shropshire (1 out of 1 farm)

  Staffordshire (1 out of 2 farms)

  Norfolk (1 out of 2 farms (but confirmed under glass, on a non-everbearer crop (site 6))

  Kent (2 out of 3 farms)

  Yorkshire (1 out of 2 farms)
- WFT was not found in samples from the following counties (but this does not mean that they are absent from these counties, e.g. WFT was confirmed in consultancy samples sent to ADAS from Scotland in 2005):

  1 farm in Cambridgeshire

  1 farm in Derbyshire,

  1 farm in Angus, Scotland

  1 farm in Perth, Scotland

  2 farms in Northumberland
- WFT was confirmed on a range of everbearer strawberry varieties: Everest, Flamenco, Jubilee, Milan and Pellegrino. WFT was not confirmed on Diamante or Evie, but WFT was not found on other varieties grown on the same farms as these varieties (sites 3 and 10), thus the incidence of WFT is likely to be linked with the site rather than

the variety.

- WFT was found in crops where the plants had been kept over winter in the field from the previous year, and also in new plantings. However, results suggested that WFT was more of a problem in fields where WFT had been confirmed in 2005 (sites 1, 2, 4, 6, 18) and on plants or beds kept for a second season in 2006 (sites 1, 4, 6, 18).
- Site 3 was the only site where WFT had been confirmed in 2005, but was not found in the same crop kept over into 2006. However, numbers of thrips in the flowers sent from this site were too low on 9 and 21 August, to give a reliable indication of the range of species present.
- Where *A. cucumeris* was being used in glasshouses, on non-everbearer crops, WFT was confirmed at one farm (site 6) but not the other (site 17), and WFT had been confirmed at both sites in 2005. Thrips control was very good in glasshouses at both sites in 2006, whereas severe problems had occurred before the growers started using biological control, and before the SOLA for the use of Tracer (spinosad) became available for strawberry.
- Where *A. cucumeris* was being used in tunnel-grown everbearers, most growers also needed to use pesticides, e.g. Tracer for thrips or Talstar/Starion (bifenthrin) for other pests e.g. blossom weevil or capsids. *A. cucumeris* was often used primarily for tarsonemid control on everbearers, often as a single release of 40-60 per m^2. This rate is likely to have been inadequate for thrips control at some sites (recommended rates for thrips control are repeated releases of 50-100 per m^2 from the presence of first flowers, sometimes following introduction of slow-release sachets pre-flowering). WFT was not present at all sites using *A. cucumeris*.
- Many growers who had released *A. cucumeris* had also used pesticides to control either thrips and / or other pests such as blossom weevil or capsids. These pesticides (e.g. Talstar) would have been lethal to *A. cucumeris*. The regular fungicide programmes used by all growers are also likely to have had adverse effects on *A. cucumeris*.

Table 1. Presence of WFT on 18 farms in 2006, strawberry variety, planting date, age of bed and whether or not biological control of thrips was being used (NDA = no data available).

Grower/ site	County	Date sampled in 2006	WFT in sample 2006?	WFT confirmed in 2005?	Field number, variety & year planted	Year beds made up	Biocontrol used for thrips / tarsonemids?
1.	Herefordshire	6 June	Yes	Yes	1. Everest 2005	2005	*Amblyseius cucumeris*, but not in sampled fields in 2006
		7 July	No	NDA	2. Jubilee 2006	2006	
		7 July	Yes	NDA	1. Everest 2005		
		11 Aug	No	NDA	2. Jubilee 2006		
		14 Sep	Yes		1. Everest 2005 2. Jubilee 2006		
		28 Sep	Yes		1. Flamenco 2006		
2.	Staffs	7 July	Yes	Yes	1. Flamenco 2006	2006, sterilised soil	No
		7 July	Yes	NDA	2. Jubilee		No
		2 Aug	Yes	NDA	1. Flamenco 2006		
		19 Aug	Yes		1. Flamenco 2006		
		11 Sep	Yes		1. Flamenco 2006		
3.	Perth, Scotland	12 June	No	Yes	1. Diamante 2005	2005	*Amblyseius cucumeris*
		9 Aug	No	Yes	Milan 2006	2002	*Amblyseius cucumeris*
		21 Aug	No	Yes	Evie 2006	NDA	*Amblyseius cucumeris*
4.	Shropshire	8 July	No	Yes	1. Flamenco 2005	2005	Not in 2006
		11 Aug	Yes		1. Flamenco 2005		

		14 Sep	Yes		1. Flamenco 2005		
5.	Derbyshire	17 July	No	NDA	1. Everest 2005		*Amblyseius cucumeris*
		2 August	No		2. Everest 2006		

Table 1 (continued)

6.	Norfolk	14 July	Yes	Yes	Glasshouse site 1.		*Amblyseius cucumeris* good control.
		14 July	No		Glasshouse site 2.		*Amblyseius cucumeris*
		14 July	No		Tunnel site 2.		*Amblyseius cucumeris*
7.	Herefordshire	25 July	No	NDA	NDA (organic crop 2006)	2006	NDA
		25 July	Yes	NDA	Pellegrino 2006	2006	NDA
8.	Cambs	27 July	No	No	Everest 2006	2006	Not for thrips. *Phytoseiulus* used for spider mite.
		28 July	No		Elsanta 2006		
9.	Norfolk	27 July	No	NDA	Jubilee 2006	Sterilised 2005	*Amblyseius cucumeris*
10.	Staffs	28 July	No	No	Evie 2006	2006	*Amblyseius cucumeris*
		28 July	No		Evie 2006		
		28 July	No		Everest 2005		
		28 July	No		Evie 2005		
11.	Angus, Scotland	11 Aug	No	NDA	Everest 2006	2006 (bags)	*Amblyseius cucumeris*

12.	Kent	30 Aug	No	No	Everest 2005	Sterilised 2005	Not for thrips. *Phytoseiulus* used for spider mite.
13.	Yorkshire	30 Aug	Yes	NDA	Milan 2006	Sterilised 2006	NDA
14.	Kent	31 Aug	Yes	No	EMR strawberry breeding plots	NDA	No
15.	Northumberland	6 Sep	No	No	Milan 2006	NDA	
16.	Northumberland	16 Sep	No	No	Milan 2006		*Amblyseius cucumeris*
17.	Yorkshire	21 Sep	No	Yes	Glasshouse Elsanta 2006		*Amblyseius cucumeris* good control.
18.	Kent	11 Oct	Yes	Yes	Jubilee 2006	1. 2004 2. 2005	*Amblyseius cucumeris*

Results and Discussion –case studies

Case study visits were made to three farms, in Norfolk, Kent and Herefordshire, between 12 July and 11 October 2006. At site 1 in Norfolk the crop was not an everbearer but was included in the case study visits as it was considered that useful information could be gained on the successful biological control of WFT within an IPM programme under glass. Site 2 in Kent was included as it was the only site where WFT was confirmed on everbearers where biological control methods had been used for thrips during the 2006 season. Site 3 in Herefordshire was included as WFT had been confirmed on everbearers during 2006 and biological control for thrips had been used on the farm in 2005, or on other fields on the farm during 2006.

Table 2. Case study summary, Site 1: Norfolk (glasshouse crop, in raised troughs). Date of visit: 12 July 2006, with Clare Sampson from BCP Ltd

Variety & planting date:	Varieties: Lambada, Dar Select, Sonata. Crop planted in August and picked until Christmas. Same crop picked end March/April and pulled out in June. Short-term crop planted 2nd week June, cropped mid-June to August.
Source of plants:	information not available
Use of *A. cucumeris*:	August-planted crop: sachets at 1 per 2 m^2 at planting. At flowering (i.e. 10-14 days after planting), single direct release at 50 per m^2. (100 per m^2 in hotspots). Further introduction of sachets in following February when heating turned back on, followed by direct release at 50 per m^2 about 3 weeks later. On June-planted crop, one direct release at 100 per m^2 (cheaper option than sachets for short-season crop, and OK as plants were in flower when planted).

Other biocontrols used:	Preventive *Amblyseius californicus* for spider mite, followed by *Phytoseiulus persimilis* and *Feltiella acarisuga* when spider mites seen (sulphur burning for powdery mildew when limited to 2-3 hrs per night proved OK for *Phytoseiulus*). *Encarsia formosa* for whitefly. 1 per m^2 per week for 6 weeks from April (after Oberon in Feb, see below). Works very well now sulphur burning time at night reduced.
Naturally occurring biocontrols:	None seen.
Flower/ fruit damage by WFT:	Some blackening to centres of flowers (i.e. young fruit), bronzing to fruit, and brown tracking on fruit under calyx but confined to hotspots at ends of some rows.
Success of IPM programmes:	Very good. WFT control has been excellent since moved over to IPM, using *A. cucumeris* (prior to that, before Tracer available, no control with Dynamec or Talstar and suffering significant crop losses). Main problem is now aphids, as sulphur is harmful to *Aphidoletes aphidimyza*.

Pesticides used:	• Used spiromefisen (Oberon) at start of each crop to clean up spider mite and whitefly. The SOLA for Oberon for use on protected strawberry is useful in IPM as too cool for *Encarsia* in February and sulphur is harmful to *Encarsia*. When used in February, it is persistent against whitefly until March/April. Experience indicates that it is safe to use *A. cucumeris* in sachets 1 week after Oberon, and as direct releases 2 weeks after. Safe to release *A. californicus* 1 week later. However, some strawberry flower damage recorded after Oberon during 2006, so in future its use will be limited to certain varieties in early spring. As an alternative, Eradicoat will be used for early season whitefly control on Oberon-sensitive varieties. • Tracer for WFT control in hotspots at ends of rows. • Sulphur for powdery mildew – limited to 2-3 hrs per night. • SBI (Stan Brouard Plant Invigorator) used against powdery mildew, aphids and spider mites. Ineffective against spider mite, effective only on aphids it made contact with, and largely ineffective against powdery mildew. Killed all *Feltiella* and most *Phytoseiulus*. Will avoid in future.
Other comments:	The glasshouse was previously used for growing chrysanthemums, so WFT was 'inherited' when started to grow strawberries. In 2005, before started using *A. cucumeris*, WFT caused severe damage (fruit bronzing and mis-shapes due to shrivelling around seeds) and a lot of fruit had to be thrown away.
Thrips species confirmed:	100% WFT in flowers (8 out of 8 specimens) collected 12 July 2006.

Table 3. Case study summary, Site 2: Kent (everbearer crop under Spanish tunnels, in peat bags). Date of visit: 11 October 2006

Variety & planting date:	Jubilee (in 2 adjacent fields), planted last week in March, 2006. Jubilee re-planted every year as it is a premium variety. However, beds and peat bags are kept for 2 years: Field 1: originally planted with Jubilee in 2004 in soil. In 2005, soil covered with Mypex and new peat bags put onto beds. March 2005 re-planted. Beds and bags kept over winter after pulling out the plants. Re-planted into old bags March 2006. Bags will be replaced for 2007 planting. Field 2: originally planted with Jubilee in soil in 2005. Crop pulled out winter 2005 and Mypex put down over soil. New peat bags put onto beds. New Jubilee crop planted March 2006. Bags will be kept over winter for the 2007 planting. Grower suspects WFT over-wintered in both fields as had WFT problems in 2005.
Source of plants:	Dutch propagator. Grower considered they were pest-free when arrived.
Use of *A. cucumeris*:	Direct release 2^{nd} week April, 40-50 per m^2. * Repeated about 3 weeks later. • NB this is the rate often used for tarsonemid control but is lower than the rate recommended by the biocontrol suppliers for thrips control.
Other biocontrols used:	Used *Phytoseiulus* for spider mite control earlier in the season but now killed by pesticides used against thrips.
Natural enemies:	None seen.
Fruit damage by WFT:	Grower estimated at least 10% losses during 2006 due to reduced fruit quality. Mis-shapen fruits and fruit cracking considered to be caused by WFT. (Jubilee is usually a very regular-shaped fruit).

Success of IPM programmes:	Grower considered that *A. cucumeris* is effective when thrips numbers are low, but loses control when numbers increase in warmer weather. Gave adequate control in 2005, together with 2 applications of Tracer. Grower has tried nematodes (*S. feltiae*) as foliar sprays (twice per week) in 2004 for thrips control. But not sure whether they worked, and had difficulty keeping the plants wet for 24 hrs after application, as advised by the supplier. Capsids are a problem every year in late July/August. Grower uses Talstar for control. This would disrupt IPM.
Pesticides used:	Thrips suddenly increased in hot weather in June 06, so abandoned biocontrol programme and used pesticides: • Tracer (spinosad) used 3 times • Talstar (bifenthrin) • Dynamec (abamectin) • Pyrethrum 5 EC (pyrethrins) Fungicides – potassium bicarbonate (as curative treatment) and sulphur for powdery mildew.
Thrips species confirmed:	100% WFT confirmed in flower samples (20 out of sample of 20).

Table 4. Case study summary, Site 3: Herefordshire (everbearer crop under Spanish tunnels, in soil). Date of visit: 28 September 2006

Variety & planting date:	Flamenco, planted 2004
Source of plants:	UK propagator. Grower first had thrips problems in 2003 and considers they might have come in on plants imported from USA. But these were hot water treated which should have killed any thrips.
Use of *A. cucumeris*:	Sachets used in this field in 2005, in biocontrol company trial (grower does not know what rate was used). Did not control thrips adequately and pesticides were necessary. Thus did not use *A. cucumeris* on this field in 2006, due to history of WFT on the field and to availability of Tracer. Direct releases used in other fields this year, for tarsonemid control (one or two releases at 40 per m^2). Has used both shaker bottles (direct release system) and sachets ('controlled release' system) but prefers the bottles as following the biocontrol company trial in 2005, he is not convinced of benefits of 'slow release' from the sachets.
Other biocontrols:	None used in this field this year, though have been used elsewhere on farm (*Phytoseiulus*).
Natural enemies:	Grower has seen *Orius* (or similar bugs), lacewings and predatory mites (thought by the grower to be typhlodromids ('typhs*). * predatory mites were present in the flowers sent to ADAS for thrips identification in 06 and these were confirmed as *Amblyseius californicus*. These may have been naturally occurring, or may have originated from the young plants, as they were released in propagation (licence for release of *A. californicus* is only under full protection).
Fruit damage by WFT:	Fruit bronzing affected *c.* 25% of crop – grower saw this as the main thrips damage. Bronzed fruit can only be sold through wholesale outlets which means they only go for about 50% of the price that would be achieved for a supermarket outlet.

Success of IPM programmes:	Overall pest situation better this year than it was last year, but whether this is due to the season or the actions taken this year is not clear. Tracer applications were timed to control thrips outbreaks early in the season, but a later attack now seems to be developing (2/flower or more estimated on date of visit). However, the grower does not expect problems to continue much into October as temperatures start to fall. Although this is the last year of the crop, the grower is considering a final application of Tracer (the 3rd this season) as a late season clean up to help reduce any overwintering populations. Elsewhere on the farm, *A. cucumeris* (used for tarsonemids) has contributed to control of thrips, and grower considers it also had some impact on spider mite*. (* as *A. californicus* were found to be naturally occurring, it is likely that this predator was contributing to spider mite control more than the *A. cucumeris*). *Phytoseiulus* has also contributed to spider mite control.
Pesticides used:	• Dursban (chlorpyrifos) applied pre-flowering as general clean-up. • Tracer (spinosad) applied as 2 spray programme starting at at 1st flower (July). • Talstar (bifenthrin) applied August when crop in full flower. Fungicides – range used including Teldor (fenhexamid), Rovral (iprodione) and potassium bicarbonate. Nimrod (bupirimate) and Systhane (myclobutanil) can be used for mildew control, but the grower tends to use sulphur as this has no harvest interval. However, grower has observed that sulphur 'slows down' the biocontrol agents.
Thrips species confirmed:	100% WFT confirmed in flowers collected on day of visit (19 confirmed out of a sample of 19).

Conclusions from work in Objective 1

- WFT is widely spread throughout England.
- WFT was not found in samples from Scotland in 2006 but this does not confirm that they are absent (WFT were confirmed in consultancy samples sent to ADAS from Scotland during 2005).
- Results suggest that WFT is more of a problem in fields with a history of WFT and where plants or beds are kept over from one year to the next.
- WFT was also confirmed on a few new plantings and on sterilised beds. On one farm (site 1), WFT were not confirmed in sequential samples from the newly planted field until September 2006. It is suspected that the WFT migrated from the adjacent field, which had a history of WFT, and where WFT was confirmed in sequential samples from June 2006.
- Use of *A. cucumeris* in glasshouse strawberries was successful in 2006 at sites where WFT had been a severe problem in 2005, when pesticides had been unsuccessfully used for control (and before Tracer was available for use on strawberry). Other pests were adequately controlled in the glasshouses, either by biological control agents or by pesticides compatible with IPM.
- Use of *A. cucumeris* in tunnel-grown everbearers gave unreliable thrips control at some sites, where pesticides had been used for control of either thrips or other pests. However, WFT was not present at all sites using *A. cucumeris*. *A. cucumeris* were mainly introduced on everbearer crops at the rate used for tarsonemid control. Thus the predators are likely to have been released too late and at inadequate dose rates and frequency for thrips control at most sites. Pesticides used for thrips and other pests and diseases on most everbearer crops would have had adverse effects on *A. cucumeris*.

Objective 2

Determine the pupation sites of WFT during the summer period in everbearer strawberry fields and the implications for control strategies (EMR).

Methods – Field experiments

This experiment was undertaken on an everbearer strawberry crop at East Malling Research; since strawberry plantations at EMR have few problems with WFT the pest was released from glasshouse cultures. Each plot consisted of 20 plants in a double row bed grown through polythene mulch. Beds were planted at 3.6 m centres and there were 5 m gaps between plots in the rows. Due to the high temperatures in summer 2006, these strawberry plants stopped flowering in July at the time the pupation experiment was planned to begin. Since it is not possible to obtain high populations of WFT on non-flowering strawberry plants, several attempts were made to encourage the plants to recommence flowering; the whole planting was de-fruited and de-runnered in early July, and the tops of the plants in part of the planting were strimmed off on 20 July. However, neither of these strategies was very successful and very few flower clusters developed. The plants were also sprayed with Talstar (bifenthrin) on 27 July to remove predators (mostly *Orius* spp) from the plants. Because the plants were not flowering well, two different experiments were set up to investigate thrips pupation sites on this plot. The first used the established, lightly flowering plants and the second some newly planted, small, vigorously growing and flowering plants.

i). Cages were constructed over two sets of 10 established plants and the adjacent alley and covered with horticultural fleece. Plots were selected that had the largest number of flowers/flower buds. WFT (adults and larvae) were released into these cages on 10 August. WFT were reared on potted broad bean plants in a glasshouse at EMR and released by placing parts of these infested bean plants onto the strawberry plants and allowing the WFT to disperse naturally. It was anticipated that these larvae would develop normally on the strawberry plants and then pupate; adults that developed from any pupae in the samples taken from the plots would then be captured on sticky traps (see below). Numbers of thrips (adults and larvae) in a sub sample of bean shoots were counted at the time of release to estimate numbers of thrips released onto the strawberry plants.

ii). Small potted flowering strawberry plants were obtained and planted on 16 August through the polythene mulch in the 5 m gaps between the established plots. Five sets of 10 plants were planted and caged as above. Two of these cages were infested with WFT on 18 August (experiment 1) and all five were infested on 31 August (experiment 2). Samples were collected on 31 August for experiment 1 and on 13 September for experiment 2.

In both experiments plants received routine irrigation. No fungicides or insecticides were applied during the experiments. Samples of soil, straw and plants were taken from each cage after allowing a suitable period for thrips pupae to develop from the stages released, based on temperature records from the EMR meteorological station, and published data on the life cycle of WFT (e.g. Robb, 1989). Samples were taken from different positions inside each cage to assess numbers of WFT pupating. Plants were cut off at ground level and soil samples were taken from directly underneath the plant, underneath the polythene mulch close to the planting hole, and from soil under the straw in the alleys; these samples were approx 20 cm deep and taken using a 10 cm diameter soil corer. For the soil samples under the polythene and under the straw, 2 cores were taken for each sample. A sample of straw (*c* 30 x 25 cm area) and a plant sample were also taken. Two samples in each position were taken from each cage. Samples were collected in polythene bags and transported to the laboratory where they were placed individually into sealed plant propagators (35 x 22 x 18 cm). A yellow sticky trap (26 x 5 cm) was hung vertically from the inner surface of the lid of each container to catch any thrips adults emerging from pupae that had been in the samples. Containers were kept in a constant temperature (CT) room at 20ºC with a 16L:8D photoperiod and samples were kept moist by misting with a hand sprayer. After a period calculated to allow any pupae in the samples to emerge as adults (more than 7 days at 20ºC) adult thrips caught on the sticky traps were counted. An assessment of numbers of thrips in the planting at the time samples were taken was also made.

Results – field experiments

i). In the established plants that had stopped flowering, although WFT had been released in the plots, only 3 adults and one larva were found in a sample of 16 folded leaves and 4 fruit clusters taken on 15 August. Consequently this experiment was terminated and no soil samples were taken.

ii). In the first experiment on the newly planted strawberries, it was estimated that c 90 WFT had been released per strawberry plant on 18 August. Only one WFT was caught on the sticky traps from the field samples, and this was from a soil sample taken from under the polythene of the raised bed. At the time the samples had been taken very low numbers of WFT were found in samples of flowers and young fruits (mean of 1.2 adults plus larvae in 17 flower/fruit samples).

In the second experiment it was estimated that *c* 150 WFT had been released per strawberry plant. Two samples of each type described above were taken each of the 5 cages. A total of 51 adult WFT were caught on the sticky traps; 49% of these were recovered from soil taken from under the plant, 37% from soil under the polythene, 12% from the straw and 2% from the soil under the straw layer. At the time the soil samples were taken, mean numbers of thrips on the plants were 1.4 and 0.9 adults plus larvae on 50 flowers and on 50 young fruits respectively.

Methods – Glasshouse experiments

Since it had not been possible to establish large populations of WFT on the strawberries in the field experiments at EMR, three artificial raised strawberry beds were created in a glasshouse compartment at EMR to enable an additional experiment to be undertaken. Each 'bed' consisted of a central container (100 x 80 cm) within a larger waterproof base (180 x 80 cm). The central container (the raised bed) was filled with compost and then covered with polythene sheeting, the ends of which were placed on the bottom of the outer base unit. Compost was placed on this polythene so that the compost layer in the base unit was *c* 10 cm lower than that in the inner container. Straw was placed on the surface of this outer compost to mimic the field alley situation. Six holes were cut into the polythene covering the inner container and a flowering strawberry plant placed into the soil through each hole. The plants were 40 cm apart between the rows and 20-30 cm apart within the rows. The compost in the inner polythene-covered containers was watered by timed drip irrigation. Compost in the outer straw-covered area was watered by hand. WFT were released on the plants as described for the field experiments on 18 September and 29 September.

In the first experiment on 23 September, samples of compost from under the plant, under the polythene and under the straw and samples of straw (12 of each) were taken, as in the field experiment, and thrips emergence monitored on yellow sticky traps in sealed boxes in the CT room.

In the second experiment emergence traps were used *in situ* to monitor thrips emergence. These traps consisted of clear plastic boxes (14 x 8 x 5 cm) with a piece of yellow sticky plastic attached to the base inside the box with electrical insulating tape. On 12 October the boxes were positioned upside-down on the soil or straw surface at the same positions that had been used for the extracted samples. Three traps were positioned over the planting hole, 3 on the soil under the polythene and 2 each on the straw and on the soil under the straw. The traps were left in place for 10 days and then the yellow sticky plastic removed and numbers of thrips adults counted. Soil samples were also collected on 12 October in this experiment from the same locations but associated with different plants, and the totals of WFT emerging in the two trapping systems compared.

Results –glasshouse experiments

In the first experiment it was estimated that *c.* 200 WFT had been released per strawberry plant. Twelve samples of each type were taken. A total of 110 WFT were caught on the yellow sticky traps; 60% of these were from soil samples taken from under the plants, 15% from soil under the polythene, 12% from the straw and 7% from the soil under the straw.

In the second experiment, where *c.* 200 WFT had been released per plant, a total of 21 WFT were caught in emergence traps; 71% of these were from soil under the plant, and 9% from each of soil under polythene, straw and soil under straw. In the extracted soil samples in this experiment only 6 WFT were caught on the sticky traps; 3 were from soil under the plant and 2 from the straw.

Methods – Field experiment at grower site in Kent

In the case study undertaken for Objective 1 by ADAS, a plantation in Kent (site 2) was found to have a severe infestation of WFT. Here the strawberries were in grow bags placed on previously used raised beds that had been covered with Mypex sheeting. It was decided to use this site for an additional experiment.

On 16 October samples of soil from the grow bag from the planting hole, of soil under the straw and of straw (5 of each type) were taken from this site and returned to the CT room at EMR to assess emergence of thrips adults. Numbers of thrips adults on the sticky traps were counted on 30 October. On 18 October emergence traps were also set up at this site. These traps (18 x 11 x 6 cm) with yellow sticky plastic (10 x 8.5 cm) attached to the bottom with electrical tape, were placed over the planting hole (10), over holes cut in the grow bags close to the planting hole (10), on the straw and on the soil under the straw (5 in each position). Also the Mypex sheeting was pinned back slightly and traps placed over the newly exposed soil surface (5). Seven plants were cut at ground level and taken back to the lab where thrips were washed off the leaves and flowers/fruits separately and counted.

In another area on this farm the grower had removed the plants from the grow bags but was retaining the bags for replanting in 2007. Five emergence traps were placed over the planting holes in bags in this area. Emergence traps were collected on 24 October and numbers of thrips on the yellow sticky plastic counted.

Results –grower site in Kent

In the soil samples that were returned to the CT room 15 WFT were caught in the sticky traps; 40% of these were from soil under the plant and the remaining 60% from the straw samples. In the emergence trapping, 259 WFT were caught in the traps. Correcting for the difference in numbers of samples taken from the different positions, 60% of thrips emerged from soil from the planting hole, 27% from elsewhere in the grow bag, 1% from the straw, 1% from soil under the straw and 12% from under the Mypex. However, at the time the samples were collected, much of the soil under the straw was flooded and the straw was very wet, and this may have affected thrips survival. In the plant leaf samples a mean of 6.3 adults, 4.7 2nd instar larvae and 0.1 1st instar larvae per leaf were recorded; in the fruit/flower samples the numbers were 4.0, 9.0 and 1.7 per fruit/flower respectively. One pupa was found in the flower/fruit samples; pupae were only rarely recorded from plant material in all the experiments.

In the plot where the plants had been removed a total of 15 WFT were caught in the five traps placed over the empty planting holes.

Conclusions from work in Objective 2

- The low numbers of flowers and small populations of WFT that established in the field at EMR, the artificial nature of the glasshouse experiment and the unconventional growing system at the farm in Kent constrain the confidence with which individual results can be interpreted. However, taken together all the experiments indicated that the greatest number of WFT pupated in the soil directly under the plant and in the soil close to the plants within the raised beds or grow bags.
- Generally, low numbers of emerging adults were found in samples of straw or soil

under the straw in the alleys. Very few pupae were recorded on plant material during these and other (Defra funded) experiments with WFT on strawberry undertaken at EMR, indicating that the majority of WFT second stage larvae drop to the ground to pupate.

- This pattern of distribution of pupation sites will have a bearing on the possibilities for biocontrol strategies against WFT pupae.

Objective 3

Determine whether WFT overwinter in everbearer strawberry fields and if so identify when they emerge (EMR & ADAS).

Materials and Methods

Kent field site

This experiment was undertaken on an everbearer strawberry planting at EMR in 2006. Each plot consisted of 20 plants in a double row bed grown through polythene mulch. Five cages were constructed and covered with horticultural fleece on 27 September; the cages covered the experimental plants and the adjacent alley. WFT from a glasshouse culture were released onto plants as described in Objective 2. Releases were made on 27 September, 4 and 2 October and 9 November 2006. Two cages received only two WFT introductions and the remaining three received all four introductions. Numbers of WFT on the beans used to infest the plots were counted on a sub sample of beans on 2 release dates (4 Oct and 9 Nov); mean numbers of adults and larvae per stalk were 2 and 65 (4 Oct), and 6 and 32 (9 Nov) respectively. Since 2 bean stalks were released per strawberry plant on these dates at least 200 WFT (mixed stages) were released on each plant. On 9 November, before the final WFT release, numbers of thrips on the caged strawberries was assessed. Samples of 10 flowers were taken from three cages and a total of 6 adults, 13 2nd instar larvae and 10 1st instar larvae were found; this indicated that populations had established but were not at very high levels. In addition to the caged releases, three grow bags taken from the grower site that was heavily infested with WFT (see Objective 2) were placed close to the plants in three other un-caged plots on 31 October. Cages were removed from the covered plots on 22 November 2006, by which time it was expected that any WFT present would have entered their overwintering sites. Removing the cages ensured that the natural microclimate around the plants was not altered during the winter months.

In early March 2007, yellow and blue sticky traps were hung on stakes in the plantation above the plants and close to areas where WFT had been released in 2006. Initially only 6 traps were hung (2 yellow and 4 blue). On 8 March these traps were replaced and additional traps hung so that there were 14 traps (7 yellow and 7 blue) in the planting. These traps were replaced on 16 and 27 March and on 12 April. On 12 April an extra 11 traps were placed in the planting (so there was a total of 17 yellow and 8 blue traps). After collection, the traps were stored in a cold room at 5ºC until they were inspected under a stereomicroscope to determine if thrips were present. Cages were replaced over the previously thrips-infested plants in the week commencing 26 March, with 3 traps being placed inside four cages and two in the fifth cage. On the first date that thrips were found on the traps all the thrips were removed, mounted on slides and inspected under a compound microscope to determine if WFT were present. For the later collection dates a sub-sample of thrips were removed for identification.

A Delta T® data logger was used to record temperatures in two replicate positions within the crop where WFT might be expected to overwinter around the raised beds. Probes were inserted horizontally 3 mm below the surface of the soil in the following locations:

1. In the planting hole
2. Under the polythene covering the raised bed, 5 cm from the edge of the planting hole
3. Under the straw close to the raised bed
4. Within the strawberry crown

The probes were 1 m apart in the same bed. Temperatures were recorded every hour from 21 November 2006 to 31 May 2007.

Herefordshire field site

Tinytalk® dataloggers were placed in similar locations to those used at EMR, in a commercial everbearer field in Herefordshire, to compare temperatures in this geographical area, with those recorded at EMR throughout the winter and spring. The field was the one used in the case study (site 3) undertaken for Objective 1, and WFT had been confirmed in the field on sequential dates during the 2006 season. The strawberry beds and plants were kept over the winter of 2006 and used for cropping in 2007.

Temperatures were recorded every hour from 8 November 2006 until 12 May 2007. The dataloggers were sealed inside polythene bags and placed in two replicate sections of bed, one metre apart, in the following locations:

1. In the empty planting hole (the strawberry plant was removed, to simulate a strawberry bed where plants are removed at the end of the season, but the bed retained for planting in the following season).
2. Underneath the polythene covering the bed, 5 cm from the edge of the planting hole.
3. Underneath the straw in the alley adjacent to the bed.

In all three locations, the dataloggers were buried so that the sensors were 3 mm below the soil surface.

Results and Discussion

Kent field site

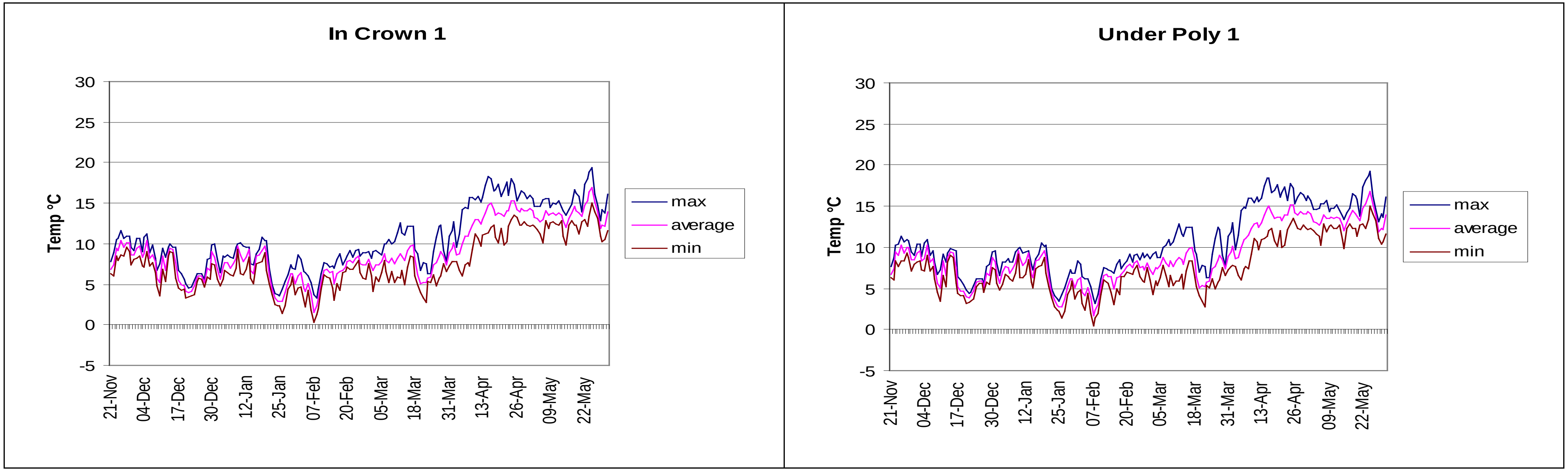
No thrips were found on the sticky traps collected on 8 March. On traps collected on 16 March 15 thrips were recorded; of these 13 were successfully removed from the sticky trap and two WFT were confirmed as present. Only 2 thrips were found on traps collected on 27 March, but were not identifiable. On 12 April 64 thrips were found on the traps; 32 of these were removed for inspection and 2 were identified as WFT. On 4 May a sub-sample of 32 thrips were removed from traps and of these 2 were identified as WFT. These results show that WFT can overwinter in the field in the south east of England. Although several hundred thrips were released per plant in the previous autumn low numbers were found on the plants in November (around 1 per flower). This may have been because the plants were no longer flowering profusely so were not suitable to enable thrips populations to increase. Grow bags from the Kent grower that had high populations of WFT had been placed around some beds to increase the numbers of WFT in the planting. However, very low numbers of WFT were caught on the sticky traps in spring, with the earliest catches being on 16 March.

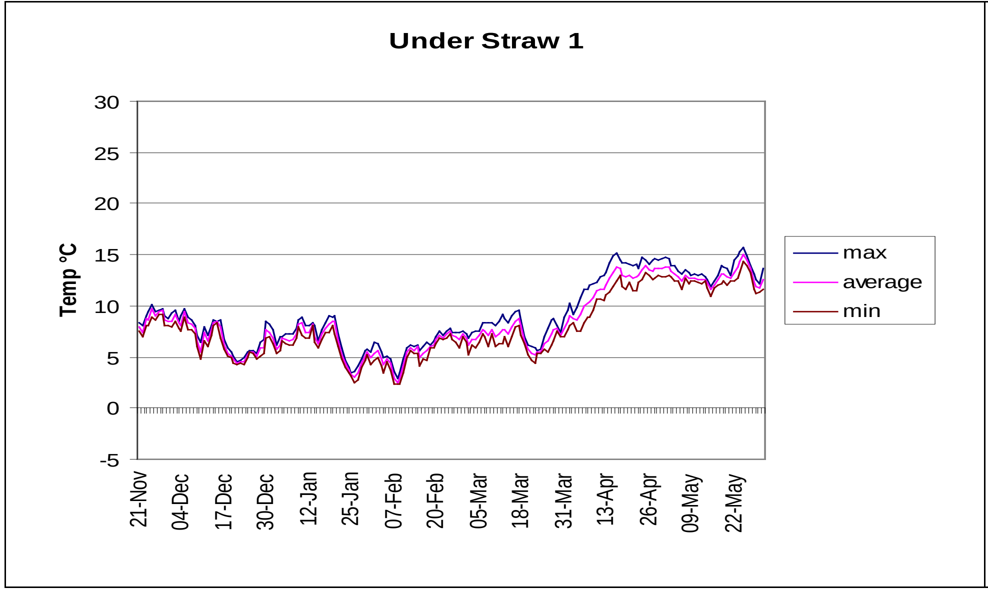
Temperatures from probes of the Delta-T® data logger in replicate position 1 are shown as an example in Figure 1. The lowest temperature recorded over the entire period was from under the soil in the planting hole in position 2 where -1.4ºC was recorded on 7 February 2007; on the same day the minimum temperature in soil replicate 1 was -1.0ºC. Lowest temperatures were also recorded on 7 February under the polythene mulch and in the plant crown (0.5ºC; -0.2ºC and 0.3ºC; -2.1ºC respectively for the two positions and two replicate recordings). The coldest temperatures recorded under the straw in the alleys were 2.3ºC and 3.1ºC in the two replicates, and these were recorded on 8 February. The straw buffered the temperature at the position of the probes such that the mean difference between the maximum and minimum temperatures recorded over the total recording period was 14.4ºC compared with 27.7ºC for probes under soil in the planting hole, 24.5ºC for probes under the polythene and 22.5ºC for probes in the plant crown; the bare soil had the largest fluctuations in recorded temperatures (Figure 1). Sub zero temperatures were recorded in at least one hourly recording on 4 and 9 days for the two replicates under soil in the planting hole, for 6 days in crown replicate 2 and for 1 day under the polythene replicate 2. However, there were always positions in the crop that were above freezing and could provide refuges for overwintering insects. It is possible that even in a colder winter than that experienced in 2006/2007 areas within the crop would remain close to or above freezing, but this possibility needs to be tested. The effect of colder winter conditions on the overwintering ability of WFT also needs to be tested.

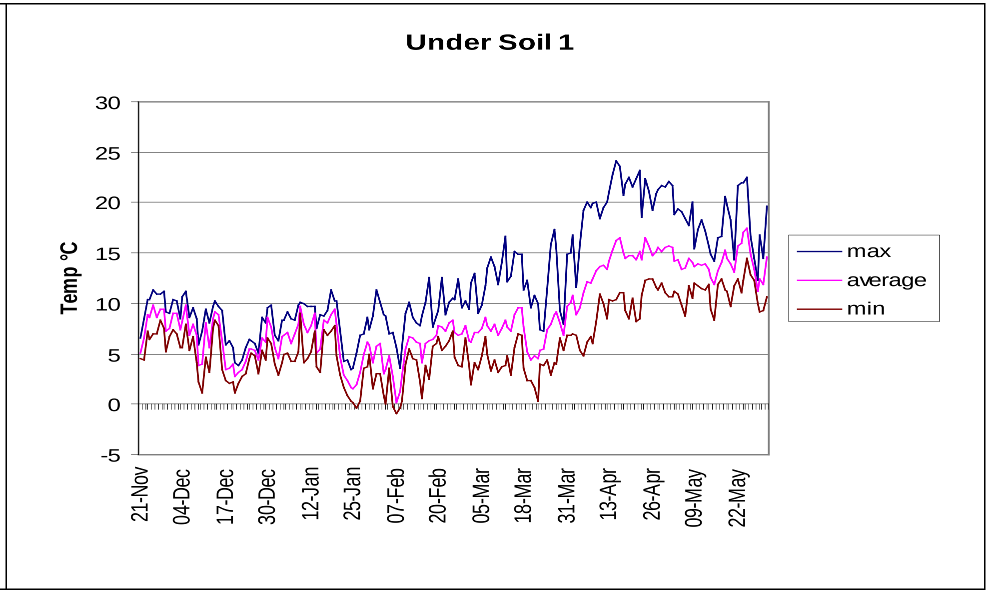
The first WFT were recorded from sticky traps collected on 16 March 2007. The maximum temperatures recorded up to 15 March were 19.3ºC in the planting hole, 17.4ºC under the polythene and 17.5ºC in the crown which were all recorded on 12 March. Maximum air temperature was 20.5ºC on that date. The highest temperature recorded under the straw was 9.3ºC on 25 November 2006. WFT can reproduce and develop at 15ºC (Robb, 1989); mean temperatures of 15ºC were recorded around mid April, so numbers of WFT would be expected to increase from that time, if suitable plant material was available as a food source.

The highest temperatures recorded between the beginning of March and the end of May were 30.0ºC on 6 April under the polythene mulch, 29.0ºC under the soil in the planting hole, 23.8ºC in the crown and 16.5ºC under the straw.

Figure 1. Temperature (°C) recordings from the Delta T® logger in a strawberry crop at EMR; daily maximum, minimum and mean temperatures are shown.



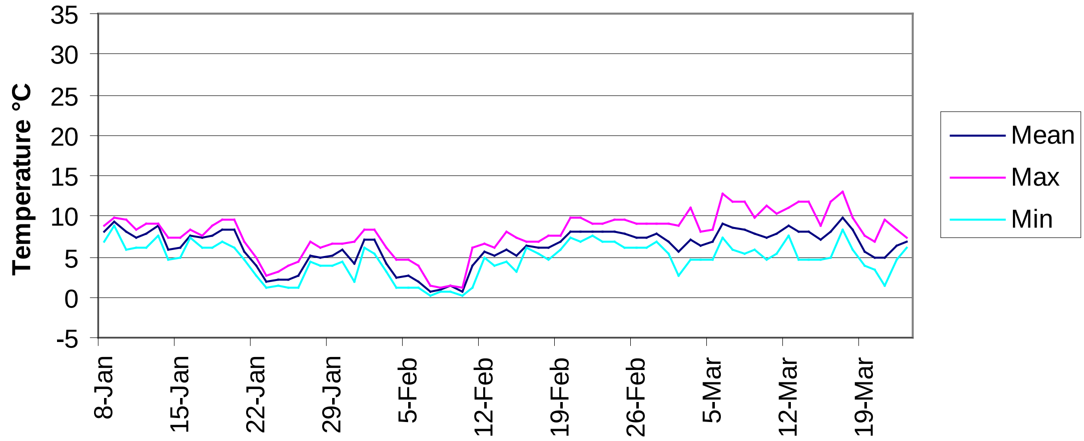

Under Straw 1
Temp °C
30
25
20
15
10
5
0
-5
21-Nov
04-Dec
17-Dec
30-Dec
12-Jan
25-Jan
07-Feb
20-Feb
05-Mar
18-Mar
31-Mar
13-Apr
26-Apr
09-May
22-May
max
average
min


Under Soil 1
Temp °C
30
25
20
15
10
5
0
-5
21-Nov
04-Dec
17-Dec
30-Dec
12-Jan
25-Jan
07-Feb
20-Feb
05-Mar
18-Mar
31-Mar
13-Apr
26-Apr
09-May
22-May
max
average
min

Herefordshire field site

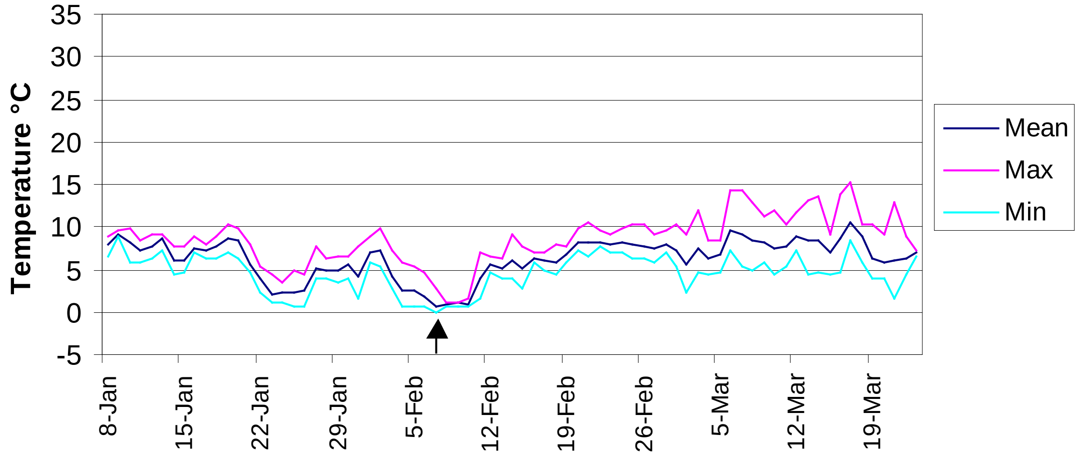
Recorded temperatures in the commercial strawberry field in Herefordshire remained mild throughout the monitoring period, from 8 November 2006 to 12 May 2007. The coldest period was during February and March. However, the lowest temperatures (down to -5°C) were recorded between mid-February and mid-March by one of the dataloggers from one of the planting holes, which had been pulled out by a wild animal and left exposed in the alley between the beds. Therefore this result was disregarded. The replicate datalogger in the second planting hole indicated that temperatures did not fall below freezing during the same period, with temperatures ranging from 0.3-13.1°C between 8 January and 19 March (Figure 2).

Figure 2. Mean, maximum and minimum temperatures (°C) recorded in the planting hole between 8 January and 19 March 2007, in the commercial strawberry field in Herefordshire



The temperature range recorded by the dataloggers under the straw in the alley between the beds was similar to those in the planting hole between 8 January and 19 March, ranging from 0.7-12.8°C (Figure 3). However, as at the Kent site, minimum and mean temperatures under the straw were slightly higher than in the planting hole and under the polythene during the coldest period in February (Table 5). Unlike at the Kent site, only one sub-zero temperature was recorded at the Herefordshire site, by one of the dataloggers under the polythene, when −0.1°C was recorded on 7 February (Figure 3).

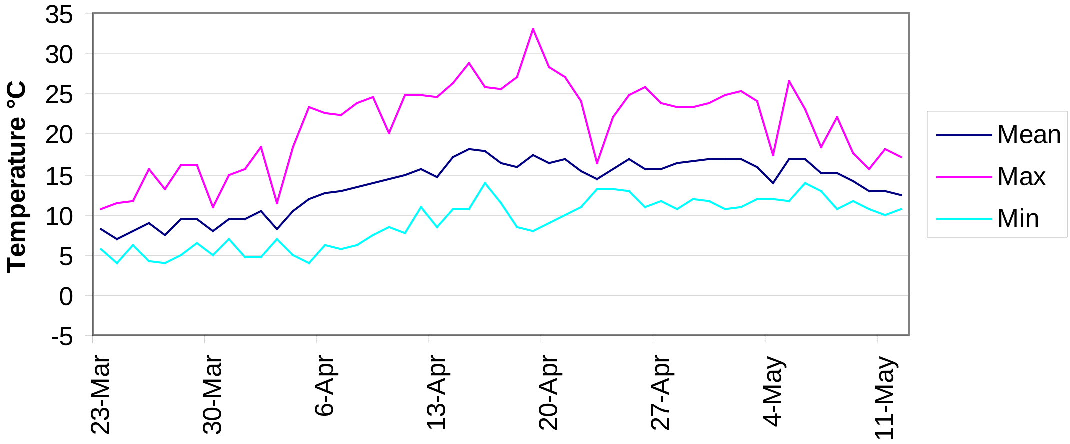
Figure 3. Mean, maximum and minimum temperatures recorded under the polythene covering the bed, between 8 January and 19 March 2007, in the commercial strawberry field in Herefordshire. Arrow points to the sub-zero temperature (-0.1°C) on 7



February.

Temperatures between late March and 12 May remained mild, with a very hot spell in mid-April to early May. Mean temperatures in the planting holes ranged from 7-18°C during this period, and maximum temperatures reached 33°C in one planting hole on 19 April (Figure 4). Temperature ranges were similar underneath the polythene covering the beds and under the straw in the alleys.

Figure 4. Mean, maximum and minimum temperatures recorded in the planting hole, between 23 March and 11 May 2007, in the commercial strawberry field in Herefordshire.



The first WFT adults in the field were confirmed in strawberry flowers by ADAS on 3 May, although the grower had observed active thrips in flowers during late April. Temperatures in late April to early May had been exceptionally warm, with a mean of 14-18°C in the planting holes, under the polythene covering the bed, and under the straw in the alleys, and maximum soil temperatures had reached 33°C (Figure 4). It is likely that WFT successfully overwintered in the field from the previous season at this site.

Effects of temperature on thrips biology

Temperatures has important implications for WFT overwintering success and adult activity in spring; these are discussed below in the context of the temperature data recorded at the Kent and Herefordshire sites

Overwintering

- The coldest week during the monitoring period at both sites was 4-10 February 2007, and the coldest day at both sites was 7 February, when -1.4°C and - 0.1°C were recorded in Kent (in the planting hole) and Herefordshire (under the polythene) respectively.
- Overall daily mean, mean maximum and mean minimum temperatures in the various locations in the crop at the two sites during this period are shown in Table 5. All

mean temperatures recorded during this week at the Kent site were warmer than at the Herefordshire site, except for the daily minimum temperatures in the planting hole, which were very similar to those in Herefordshire. However, sub-zero temperatures were recorded on several occasions during this period in Kent, but on only one occasion in Herefordshire.

- At the Herefordshire site, mean temperatures were very similar in the planting hole and under the polythene. However, at the Kent site, the mean daily minimum temperatures were higher under the polythene than in the planting hole, indicating that the polythene offered some protection against the cold.
- At both sites, mean daily mean and mean daily minimum temperatures were slightly higher under the straw in the alleys than in either the planting hole or under the polythene (or in the plant crown at the Kent site). This indicates that the straw buffered low temperatures at both sites.

Table 5. Overall daily mean, mean daily maximum and mean daily minimum temperatures recorded in soil in the planting hole, under the polythene covering the beds and under the straw in the alleys in Kent and Herefordshire and in the plant crowns in Kent during the coldest week, 4-10 February 2007

Datalogger position	**Overall mean temperature °C**		**Mean daily maximum temperature °C**		**Mean daily minimum temperature °C**	
	Kent	Hereford	Kent	Hereford	Kent	Hereford
Planting hole	3.1	1.6	7.5	2.6	0.9	0.8
Under polythene covering bed	3.6	1.5	5.7	2.8	2.1	0.7
Under straw in alleys	4.0	2.1	4.5	2.9	3.6	1.5
In crown of plant	3.4	-	6.0	-	1.5	-

- The winter of 2006/2007 was exceptionally mild, and WFT successfully overwintered in the field in Kent and are likely to have overwintered on site in Herefordshire. In more severe winters, the straw in the alleys may allow WFT to overwinter more successfully than in the soil under the plants or under the polythene. Thus a possible cultural control strategy for reducing WFT overwintering success might be to remove the straw from the alleys in any everbearer fields where the plants are retained over winter for cropping the following season. This strategy will be considered for research in this project in year 3, following further overwintering experiments in year 2 on a commercial strawberry field in East Anglia or the West Midlands, in consultation with the HDC, project co-ordinators and ADAS soft fruit consultants.

Adult activity in spring

- WFT adults were first found on sticky traps at the Kent site on 16 March, and were confirmed in strawberry flowers at the Herefordshire site on 3 May. However, as the Herefordshire site was not used to monitor first WFT emergence in the winter of 2006/2007, the first date of adult activity at this site is unknown. WFT adults must have been active before 3 May at this site, as both adults and larvae were present in the flowers on this date.
- All WFT life stages could possibly survive a mild winter such as in 2006/2007, by sheltering in soil or plant debris, although adults are likely to be the most cold-hardy stages (McDonald et al., 1997).
- Although WFT adults could crawl from their overwintering sites onto nearby strawberry plants, they would have to fly to reach sticky traps. Previous Defra-funded research at Keele University on WFT flight behaviour indicated that the temperature 'threshold' for take-off is 20ºC (Bennison, 2006). At the Kent site, where WFT were first recorded on sticky traps on 16 March, maximum air temperatures had exceeded 20ºC for the first time that year on 12 March, reaching 20.5ºC (Table 6). This result is consistent with the Keele University 'flight temperature threshold'. On 12 March, air temperatures were above 17ºC from 12.00-17.00 hr, and a maximum temperature of 19.3ºC was recorded in the planting hole.
- At the Herefordshire site, maximum soil temperatures in all datalogger positions had

exceeded 20ºC by 8 April (Table 6) and the temperatures in late April and early May were exceptionally warm, prior to WFT being confirmed in strawberry flowers in this field on 3 May.

- Further research in year 2 of the project will be done to compare the overwintering results from the Kent site in year 1, with overwintering success in 2007/2008 at a commercial site in east Anglia or the West Midlands. This research will give further information on temperatures when WFT adults first become active in the spring.

Table 6. Dates temperatures first exceeded 20°C at both sites in the soil in the planting hole, under the polythene covering the beds and under straw in the alleys, and in the air (Stevenson screen) in Kent

Datalogger position	**Date temperatures first exceeded 20°C, Kent**	**Date temperatures first exceeded 20°C, Herefordshire**
Planting hole	5 April	5 April
Under polythene covering bed	27 March	5 April
Under straw in alleys	Never exceeded 20°C	8 April
In air (Stevenson screen)	12 March	Air temperatures not recorded

Conclusions from Objective 3

- Soil temperatures in the commercial everbearer field in Herefordshire remained mild throughout the winter and spring period. The only sub-zero temperature recorded was -0.1°C on 7 February under the polythene covering a bed.
- In Kent sub zero temperatures recorded on several days. However, the lowest temperature recorded was only -1.4ºC under the soil in the planting hole and -2.1ºC in the plant crown.
- In the recordings taken in Kent and Herefordshire, the straw buffered the temperatures recorded from the soil under the straw during the coldest period, indicating that there are likely to be areas within the crop that remain mild even in colder winters. This

may allow WFT to survive in strawberry fields in more severe winters than those experienced in 2006/2007. Thus, removal of straw in the alleys before winter may be a possible cultural strategy to reduce numbers of overwintering WFT.

- WFT were confirmed to be present in the planting at EMR on 16 March indicating that low numbers had successfully overwintered; low numbers were caught on sticky traps in April and May, so there was no indication that the population was increasing on the plants at these temperatures
- It is likely that WFT successfully overwintered in the field in Herefordshire. The first WFT adults in everbearer flowers in the field were confirmed by ADAS on 3 May. This followed two weeks of hot weather, when mean soil temperatures were 14-18°C and maximum soil temperatures reached 33°C.

Objective 4

Using knowledge gained from objectives 1-3, design and test integrated control strategies for WFT (EMR & ADAS).

After full consideration of the information gained in earlier project objectives, and following discussions with biological control suppliers, growers and the HDC, it was decided to test the effectiveness of predatory mites against WFT in the 2007 experiments. Biological control strategies to be considered for the experiments in 2008 will be decided after consideration of the results of these experiments.

Materials and methods

Kent field site

A new area of everbearer strawberries (cv. Flamenco) was planted at EMR on 3 May 2007 for this experiment. Each plot consisted of 40 plants in a double row raised bed covered with polyethylene mulch. The plants were spaced 0.4 m apart between the rows and 0.5 m apart in the rows. Thus each plot covers *c.* 10 m^2. Each bed is 6 m apart and is located in the centre of a Spanish tunnel. The polythene will be erected on the tunnels after the experiment has begun. Plants were de-blossomed and de-runnered on 15 June, and received a pyrethrum (short persistence) insecticide on 10 July to remove predators and any species of thrips apart from WFT. There were no flowers on the plants on 3 July. By 23 July the plants were flowering well. Two biological control agents are to be tested: the predatory mite *Amblyseius cucumeris*, which is the standard agent used for thrips control on many horticultural crops, including strawberry, and *Hypoaspis miles*, a ground living predatory mite that may be able to attack the WFT pupae in the soil. There will be five replicates of each treatment. Experimental treatments will be:

1. Releases of *A. cucumeris* on three consecutive release dates.
2. Releases of *H. miles* on three consecutive release dates.
3. Releases of a combination of the two predatory mites.
4. Untreated control.

The following assessments will be made:

- Numbers of thrips adults and larvae in 20 flowers per plot, immediately before the application of the predators on each release occasion and one week after the last application.
- The proportion of WFT adults in the thrips population in the sampled flowers on each assessment date.
- Numbers and species of predatory mites in the flowers.
- Thrips damage to 20 fruit per plot (final two assessment dates only).

Herefordshire field site

An experiment was set up by ADAS on 3 May 2007 on an everbearer crop (cv. Everest) in Herefordshire, in the same field used for monitoring temperatures in Objective 3. The field had a history of WFT. The biological control agent tested was the predatory mite *Amblyseius cucumeris*. Six replicate plots were used for each treatment. Experimental treatments were:

1. *A. cucumeris* at 100 per m^2 on three consecutive release dates.
2. *A. cucumeris* at 150 per m^2 on three consecutive release dates.
3. Untreated control.

The experiment was set up when the strawberry plants had the first open flowers. Assessments were taken as described above. The host grower applied pesticides if and when needed, but liaised with ADAS on choice of product, in order to use those least harmful to *A. cucumeris*.

As both EMR and ADAS experiments are still in progress at the time of writing this report, the results will be given and discussed in the project annual report in 2008.

Technology transfer

- The results of work in Objective 1 were included, with acknowledgement, in the presentation given by Clare Sampson (BCP) on biological control of WFT in strawberries, at the British Berry Conference, 15 November 2006.
- Jean Fitzgerald gave three brief presentations on the results obtained in the first year of this project at Fruit Focus which took place at EMR on 25 July 2007.

Acknowledgements

Thanks are due to the following:

- All growers and consultants contributing to the survey, case studies and for hosting experiments.
- Biological control suppliers, in particular, Clare Sampson from BCP Ltd., for providing information on experience of integrated control strategies for WFT on strawberries.
- BCP Ltd. for providing biological control agents for experiments.
- Robert Irving, ADAS soft fruit consultant, for providing information on everbearer production systems and commercial experience of thrips and other pest management strategies.

References

Bennison, J., Maulden, K. & Maher, H. 2002. Choice of predatory mites for biological control of ground-dwelling stages of western flower thrips within a 'push-pull' strategy on pot chrysanthemum. *IOBC/WPRS Bull.* 25(1), 9-12.

Bennison, J.A., Broadbent, A.B., Kirk, W.D.J., Maulden, K. A.. & Shipp, J.L. 2004. Western flower thrips pupation behaviour on greenhouse chrysanthemums and implications for integrated control. *Abstract in Proceedings of the International Congress of Entomology, Brisbane, Australia*, 2004

Bennison, J. 2006. Exploiting knowledge of western flower thrips behaviour to improve efficacy of biological control measures. *Final report to Defra on project HH3102TPC.*

Fitzgerald, J. 2004. IPM-compatible insecticides and potential biocontrol agents for use against thrips in strawberry. *Final report for HDC project SF 60.*

Fitzgerald, J., Berrie, A., Cross, J. & Down, G. 2005. Review of biocontrol strategies and novel products for control of key pests and diseases in strawberry and raspberry. *Final report for HDC project SF 66.*

Herron, G.A. & James, T.M. 2005. Monitoring insecticide resistance in Australian *Frankliniella occidentalis* detects fipronil and spinosad resistance. *Australian Journal of Entomology* 44, 299-303.

Loughner, R.L., Warnock, D.F. & Cloyd, R.A. 2005. Resistance of greenhouse, laboratory and native populations of western flower thrips to spinosad. *HortScience* 40(1), 146-149.

McDonald, J.R., Bale, J.S. & Walters, K.F.A. 1997. Low temperature mortality and overwintering of the western flower thrips. *Bulletin of Entomological Research* 87, 497-505.

Robb, K.L. 1989. Analysis of *Frankliniella occidentalis* (Pergande) as a pest of floricultural crops in California greenhouses. *PhD thesis, University of California, Riverside*, 57pp.