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Project Report No. 568

Improving risk assessment and control of saddle gall midge (*Haplodiplosis marginata*)

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This is the final report of a 37 month project (RD-2012-3806) which started in February 2013. The work was funded by a contract for £89,547 from AHDB Cereals & Oilseeds.

CONTENTS

1. Abstract

Saddle gall midge is a sporadic, but a periodically and locally-important, pest of cereals in the UK. Severe, widespread outbreaks occurred in continuous cereals on heavy land in 2010 and 2011 with yield losses in the most severe cases reaching 70%. The occasional nature of the pest in the UK means that experience of the problem is minimal. The aims of this project were:

1. To monitor midge development in relation to meteorological data to improve understanding of the pest's life-cycle and to facilitate improved forecasting of outbreaks.
2. To measure the impact of midge infestation on yield of wheat and barley.
3. To evaluate the efficacy of a range of timings and products for midge control.
4. To use data from objectives 1–3 to propose provisional thresholds for saddle gall midge.

Soil sampling was an effective method of assessing levels of saddle gall midge and monitoring its development. Detection of midge pupation provides an early warning of adult emergence and is an important component of risk assessment for the pest. A fungal parasite *Lecanicillium* spp of midge larvae was identified and had a dramatic effect on larval development, such that few became pupae. Yellow water traps were more effective than yellow sticky traps or emergence traps at catching saddle gall midge adults. In collaboration with Harper Adams University, developmental models using soil and air temperature were evaluated and predicted the timing of pest emergence to within eight days. Also prototype pheromone traps were tested and were very effective at trapping adult male saddle gall midge.

There was no clear relationship between larval infestation and crop yield, probably due to the low level of pest infestation throughout the project. Chemical control of saddle gall midge reduced tiller infestation by up to 92% but had no impact on crop yield, indicating that damage does not always equate to loss of yield. Sprays targeted at the first appearance of saddle gall midge adults were generally most effective at reducing pest infestation but those targeted at larvae were ineffective. Lamda-cyhalothrin and thiacloprid both gave good control of the pest. A single spray of lamda-cyhalothrin generally resulted in the lowest levels of pest infestation

Levels of saddle gall midge were generally too low to make any progress on the development of threshold and there was no evidence to suggest that larval threshold of greater than 500 larvae/m^2 should continue to be used until experimental evidence suggests otherwise.

A basic IPM strategy is proposed for the pest which takes into account individual field risk, pest numbers, monitoring of pest development and the timing of adult emergence to determine the need for insecticide treatment. The project should help to reduce the unpredictability of saddle gall midge attack and help to minimise unnecessary insecticide treatment against the pest.

2. Introduction

Saddle gall midge is a sporadic, but a periodically and locally-important, pest of wheat, barley, rye and oats in the UK. Gratwick (1992) provides a description of the life cycle of the pest. The adults are red midges up to 5mm long and usually appear from late May onwards. The large egg-bearing females can be easily seen resting or laying eggs on leaves, but the relatively slim, active males are rarely seen. After mating the female lays groups of red eggs in a raft or chain like pattern on the upper or lower surface of leaves. The eggs hatch in 1–2 weeks and the larvae move down the leaf to feed on the surface of the stem underneath the leaf sheath. At first the larvae are whitish/green but become orange/red by the time they are fully grown in mid-July. They then fall to the ground, enter the soil and overwinter as larvae in tiny mud cells. Larvae that are going to become adults in that year pupate in May and emerge as adult midges 10–20 days later depending on temperature and rainfall. Other larvae may remain in the soil for one or more years, particularly if the weather during May and early June is very dry and the soil very hard. There is only one generation a year.

Larval feeding results in the formation of galls which appear as saddle-shaped depressions on the stems with a swelling at either end. It is from these that the pest derives its name. Galls interfere with flow of nutrients in the stem which can result in incomplete filling of the ear or shrivelled grain. If larvae are very numerous the galls may fuse together and the stem may be destroyed. Some ears can be lost where they become severed at the point of damage.

Severe, widespread outbreaks occurred in continuous cereals on heavy land in 2010 and 2011, from Wiltshire to the Scottish Borders, with yield losses in the most severe cases reaching 70% (A Cotton, pers. comm.). The occasional nature of the pest in the UK means that experience of the problem amongst researchers, agronomists and the farming community is minimal, when compared to more regular pests such as aphids or wheat bulb fly.

There is limited information available in the literature on saddle gall midge. This was summarised in the recent AHDB Research Review No 76 'Ecology and control of saddle gall midge *Haplodiplosis* marginata von Roser (Diptera: Cecidomyiidae) (Dewar, 2012). The review discussed life history, distribution and abundance, host plant preferences, forecasting and monitoring, crop damage and control measures. AHDB Information Sheet 50 'Saddle gall midge' summarised the main areas of the review. The Review was used to help scope the current project. Much of the literature deals with outbreaks of saddle gall midge in Europe and this project will help determine whether the findings are equally applicable in the UK.

In 2012, AHDB Cereals & Oilseeds funded a monitoring programme at a site with a known history of the pest (RD-2011-3765). Dow AgroSciences also funded the monitoring of another site as part of their Pestwatch campaign. Both sites were in Buckinghamshire. One was at Wendover where 15.4 million saddle gall midge larvae/ha were recorded and the second was at Cadmore End where 10.7 million saddle gall midge larvae/ha were found. Despite these extremely high levels of the pest in the soil there was limited, if any, crop damage. This suggests that predicting the risk of crop damage from saddle gall midge is more dependent on the timing and number of adult pests that emerge rather than the number of larvae in the soil. This is similar to the situation with orange wheat blossom midge where risk assessment is crucially dependent on the size and timing of adult midge emergence in relation to the susceptible stage of the crop. It was also interesting that the number of midge developmental stages (larvae, pupae and cocoons) in the soil declined by 94% at Wendover and 96% at Cadmore End over the season. This would be expected if adult midges emerged but there were very few pupae recorded and few midges caught on yellow sticky traps. The whereabouts of these developmental stages is important. It is possible that they were predated by birds but they may have also migrated deeper into the soil which would mean that they are still potentially available to invade future crops.

This project draws on the results of the previous AHDB Cereals & Oilseeds-funded monitoring to improve our understanding of the biology of saddle gall midge and to develop a better informed risk assessment methodology for the pest. The main objectives of the project were:

1. To monitor midge development in relation to meteorological data to improve understanding of the pest’s life-cycle and to facilitate improved forecasting of outbreaks.
2. To measure the impact of midge infestation on yield of wheat and barley.
3. To evaluate the efficacy of a range of timings and products for midge control.
4. To use data from objectives 1–3 to propose provisional thresholds for saddle gall midge.

An AHDB Cereals & Oilseeds PhD studentship (Project number 214-0002) entitled ‘Investigating the effect of natural enemies and environmental conditions on soil populations of saddle gall midge (*Haplodiplosis marginata*)’ undertaken by Charlotte Rowley at Harper Adams University began on 1 October 2013. There was close liaison between the ADAS and Charlotte Rowley throughout the life of the ADAS project and this was particularly useful in developing monitoring methods for saddle gall midge. ADAS was able to provide meteorological data to help evaluate developmental models for saddle gall midge developed at Harper Adams and also provided sites at which pheromone traps could be tested. Both research groups were also able to exchange information on the best sites at which to site field experiments.

3. Materials and methods

3.1. Monitoring midge development (Objective 1)

3.1.1. Sites

The location of monitoring sites in each project year is given in Table 1

Table 1. Location of monitoring sites 2013-2015

	2013	2014	2015
Wendover	✓	✓	✓
Sessay	✓	✓	

3.1.2. Collecting meteorological data

AHDB Cereals & Oilseeds project Monitoring saddle gall midge (*Haplodiplosis marginata*) larvae and adult emergence (PR516) provided one year's data on numbers of midge developmental stages in relation to meteorological data at Wendover, Buckinghamshire. This was repeated for three further years at the same site in Buckinghamshire and for two years in Sessay, North Yorkshire where saddle gall midge has been a frequent problem. This provided a total of four years of monitoring data for the south of England and two years of data for the north of England under contrasting weather conditions which are likely to influence midge emergence. Data loggers were used at each site to record the following information:

- Air temperature (°C)
- Soil temperature to 10 cm depth (°C)
- Relative humidity (%RH)
- Rainfall (mm)
- Soil moisture (% by volume)

Two developmental models to predict pupation and emergence of saddle gall midge were developed by Charlotte Rowley at Harper Adams University. The models were based on those described for orange wheat blossom midge (*Sitodiplosis mosselana*) by Elliot *et al*., (2009) and Jacquemin *et al*., (2014). These were based on soil and air degree day accumulations prior to pupation and emergence at sites across the country. Met data from ADAS sites were used in the models to provide the predicted dates of insect pupation and emergence at Wendover, Buckinghamshire in 2014 and 2015 and insect emergence at Sessay, North Yorkshire for 2015. Air and soil temperature data for the models were obtained from the Met Office network of meteorological stations for consistency. Comparing this data with temperatures recorded by the in-field data loggers used at the ADAS sites gave assurance that the Met Office data were comparable to site temperatures.

3.1.3. Soil sampling

The numbers of each midge developmental stage were as assessed by soil sampling between early March and mid-June in each of the three years of the project. Samples were taken every two weeks until saddle gall midge pupae were recorded and then weekly until the end of the monitoring period. In the final year of the project the length of the sampling period was extended from March until harvest by increasing the period between sampling occasions. Soil samples were taken every three weeks until saddle gall midge pupae were recorded and then weekly whilst monitoring traps were in the field before again returning to three weekly intervals until harvest. A total of 20 soil cores were taken on each sampling occasion to a depth of 30cm. This was done with a 10 cm diameter golf hole borer with samples taken between 0–10 cm, 10–20 cm and 20–30 cm. All samples were taken down the same hole. Each sample for each soil depth was kept separate. Each bag from each depth was extracted separately by soil washing using a Salt and Hollick apparatus (Salt and Hollick, 1944) followed by flotation in saturated magnesium sulphate. Numbers of earthen cells, free larvae, pupae (neonate and sclerotised) and parasitised developmental stages were assessed. By sampling at three depths it was possible to determine whether midge larvae move up and down the soil profile in response to weather conditions.

3.1.4. Monitoring saddle gall midge emergence

A range of trapping methods were compared to determine which was most effective for saddle gall midge adults. These were:

- Yellow sticky traps
- Yellow water traps
- Emergence traps
- Pheromone traps

Yellow sticky traps

The yellow sticky traps were Aeroxon greenhouse and house plant flying insect traps (10 cm wide x 25 cm long). These had a hole at one end of the trap and were secured to a cane using a twist grip and positioned at maximum crop height. Traps were changed at each visit to the site.

Yellow water traps

Yellow water traps were cylindrical, plastic containers 17 cm diameter and 6 cm deep. These had three small holes drilled approximately 1 cm down from the top of the trap so that they did not overflow. Traps were half-filled with water and a drop of detergent added to break the surface tension so that any insects trapped sunk and drowned. Traps were emptied into a plastic sieve lined with a piece of muslin. The muslin was stored in a screw top tube and returned to the laboratory for examination. The muslin was then washed into a plastic tray and the numbers of midges counted.

Emergence traps

Emergence traps were constructed from plastic seed trays (37 cm long x 24 cm wide x 6 cm deep). The bottom of the seed tray was removed and replaced with a sheet of clear polythene which was secured to the side of the trap with duct tape. The inner surface of this was coated with OecoTak A5 a non-drip insect trapping adhesive which does not set or dry. Therefore the sticky surface of the polythene faced the ground when the trap was in position. A hole was drilled in the each corner of the rim of each seed tray so that they could be secured to the ground with metal skewers. Traps were examined in the field and the number of adult midges counted.

Pheromone traps

The prototype pheromone traps were delta traps and only used in the last year of the project and were supplied by Charlotte Rowley, an AHDB Cereals & Oilseeds PhD student working on saddle gall midge at Harper Adams University. The traps used a pheromone lure based on volatile compounds emitted by female saddle gall midge (alkan-2-ols and alk-2-ylbutanoates, Censier *et al*., 2014). Two traps were placed approximately 10 m apart down a wheeling (Figure 1). The pheromone lure was placed on a sticky insert. Each week the insert was changed and the lure transferred to the new insert. The old inserts were returned to the laboratory and the number of adult midges counted.

Figure 1. Pheromone traps showing trap location in field, trap support, lure and sticky insert

3.2. Impact of saddle gall midge on crop yield (Objective 2)

Monitoring of saddle gall midge in 2012 indicated that despite high levels of pests in the soil there was limited impact on crop yield. It is important to be able to get some indication of the impact of saddle gall midge on the comparative yield of wheat and barley. The impact of the pest on individual plants/tillers was studied in comparison with uninfested plants/tillers. Up to 100 infested and 100 uninfested plants/tillers were collected at approximately GS 91 and examined in the laboratory. A total of six crops of wheat and one of spring barley were studied over the life of the project (Table 2).

Table 2. Sites from which uninfested plants and those infested with saddle gall midge were collected

Year	Crop	Location
2013	Winter wheat	Great Saxham, Suffolk
2013	Winter wheat	Sessay, North Yorkshire
2013	Winter wheat	Wendover, Buckinghamshire
2014	Winter wheat	Boxworth Cambridgeshire
2014	Winter wheat	Wendover, Buckinghamshire
2015	Winter wheat	Wendover, Buckinghamshire
2015	Spring barley	Kelso, Scottish Borders

It was intended to sample six barley as well as six wheat crops but barley sites infested with saddle gall midge were particularly difficult to locate. A number of barley sites were located in Scotland in 2015, the final year of the project, but samples were only received from one site near Kelso in the Scottish Borders. The grain number, weight per grain, grain yield per ear, straw yield, chaff yield and total tiller yield were assessed in each cereal sample. Then t-tests were used to compare infested and uninfested tillers and regression analysis was used to investigate and relationships between gall numbers and the grain yield of individual ears.

3.3. Chemical control options for saddle gall midge (Objective 3)

There are currently no label approved products for control of saddle gall midge although a number of insecticides can be applied to cereals at a time likely to coincide with the presence of midges in the crop. There is only a small window during which insecticides are likely to be effective. This is the time from egg hatch until midge larvae move beneath the leaf sheath where they feed. It is important to know which insecticides are likely to be most effective for control of the pest and how best to time these treatments.

There were four chemical control experiments during the project each comparing three products at a range of timings. The experiments were located at sites with a known history of saddle gall midge damage. The sites are listed in Table 3. At Wendover, plots were 12 m x 2 m and at Royston they were 18 m x 2 m.

Table 3. Location of chemical control experiments 2013–2015.

Year	Site	County	Grid reference
2013	Wendover	Buckinghamshire	SP 85969 08469
2014	Wendover	Buckinghamshire	SP 85969 08469
2015	Royston	Cambridgeshire	TL 3690 49087
2015	Wendover	Buckinghamshire	SP 85969 08469

The insecticide treatments compared were as listed in Table 4

Table 4. Insecticide treatments, product, active ingredient and MAPP number

Product	Active ingredient & concentration	MAPP number
Biscaya	240 g/l thiacloprid	15014
Equity	480 g/l chlorpyrifos	12465/PCS 92186
Hallmark Zeon	100 g/l lamda-cyhalothrin	12629

In 2013 and 2014 the treatment list was as per Table 5. In 2015, the treatments were changed to include programmes of sprays and these are shown in Table 6.

Table 5. Insecticide treatments at Wendover in 2013 and 2014

Treatment number	Insecticide	Insecticide timing			
		1st catch of adults	7–10 days after 1st adults	1st eggs	1st larvae
1	Untreated				
2	Chlorpyrifos @ 0.6 l/ha	✓			
3	Chlorpyrifos @ 0.6 l/ha		✓		
4	Chlorpyrifos @ 0.6 l/ha			✓	
5	Chlorpyrifos @ 0.6 l/ha				✓
6	Lamda-cyhalothrin @ 0.05 l/ha	✓			
7	Lamda-cyhalothrin @ 0.05 l/ha		✓		
8	Lamda-cyhalothrin @ 0.05 l/ha			✓	
9	Lamda-cyhalothrin @ 0.05 l/ha				✓
10	Thiacloprid @ 0.4 l/ha	✓			
11	Thiacloprid @ 0.4 l/ha		✓		
12	Thiacloprid @ 0.4 l/ha			✓	
13	Thiacloprid @ 0.4 l/ha		✓		✓

Table 6. Insecticide treatments at Wendover and Royston in 2015

Treatment number	Insecticide	Insecticide timing			Number of sprays
		1st catch of adults	7 days after 1st catch of adults	14 days after 1st catch of adults	
1	Untreated				N/A
2	Lamda-cyhalothrin @ 0.05 l/ha	✓			1
3	Lamda-cyhalothrin @ 0.05 l/ha		✓		1
4	Lamda-cyhalothrin @ 0.05 l/ha			✓	1
5	Lamda-cyhalothrin @ 0.05 l/ha	✓	✓		2
6	Lamda-cyhalothrin @ 0.05 l/ha		✓	✓	2
7	Lamda-cyhalothrin @ 0.05 l/ha	✓	✓	✓	3
8	Chlorpyrifos @ 0.6 l/ha	✓			1
9	Chlorpyrifos @ 0.6 l/ha		✓		1
10	Chlorpyrifos @ 0.6 l/ha			✓	1
11	Thiacloprid @ 0.4 l/ha	✓			1
12	Thiacloprid @ 0.4 l/ha		✓		1
13	Thiacloprid @ 0.4 l/ha			✓	1

In 2013 and 2014, treatments were timed to coincide with the first visual record of adults, eggs or larvae at the site. A spray targeted at larvae was included to confirm that this timing was ineffective for midge control. In 2015, the trigger for the first treatments was the first catch of adult midges in the pheromone traps. Subsequent treatment timings were seven or fourteen days after the initial catch of midges.

3.3.1. Chemical application

All sprays were applied in 200L water/ha using an Oxford Precision sprayer using a boom comprising four LD02 F110 low drift nozzles at a pressure of 2 bar to achieve a medium quality spray. With the exception of the experimental treatments no other insecticides were applied to the plots. All other agrochemical treatments were as per normal farm practice.

3.3.2. Experimental design and data analysis

The experimental design was a factorial plus control treatment structure in all years. The advantage of the factorial treatment structure is that it allows the three chemical treatments to be compared irrespective of when they were applied and also the four treatment timings to be compared irrespective of what chemical was applied. The interaction of these factors provides information on whether different chemicals were effective at different timings.

In 2015 the data were analysed in two ways. Firstly, a sub-set of the treatments (1–5 & 7–13) were analysed as a factorial plus control design comprising 10 treatments in total. Secondly the data for lamda-cyhalothrin treatments (1–7) were analysed as a completely randomised treatment structure comprising seven treatments. There were four replicates of each treatment in all years arranged in a randomised block design.

3.3.3. Assessments

Crop growth stage was assessed at the time of each treatment application. At approximately GS 91 a random sample 25 tillers per plot was taken to assess number of larvae and/or galls/tiller. Crop yield and specific weight in 2013 was measured with a plot combine and corrected to 85% dry matter.

3.4. Proposing thresholds for saddle gall midge (Objective 4)

This objective was a desk study which used the data generated from Objectives 1–3 together with the literature such as ‘Ecology and control of saddle gall midge *Haplodiplosis marginata* Von Roser (Diptera; Cecidimyiidae)’ AHDB Research Review No. 76 (Dewar, 2012). Ultimately it was intended that this objective would provide the basis for an integrated pest management (IPM) strategy for saddle gall midge.

4. Results

4.1. Monitoring midge development

4.1.1. Meteorological data

Meteorogical data was collected for the Wendover, Buckinghamshire site in each three years of the study and for Sessay, North Yorkshire in 2014. A data logger was also set in North Yorkshire in 2013 but a malfunction meant that data were lost. Summaries of the data collected are provided in Figures 1–12 and Table 7.

Table 7. Summary of meteorological data from Sessay and Wendover, 2013–15 (N/A = logger failure, no data available)

Weather parameter		**Sites**			
		Sessay 2013	**Wendover 2013**	**Wendover 2014**	**Wendover 2015**
Soil temperature (°C)	Max	15.9	22.1	20.6	N/A
	Min	8.0	7.6	6.0	N/A
Air temperature (°C)	Max	18.5	22.6	22.7	25.3
	Min	5.8	4.9	3.3	5.8
Rainfall (mm)	Max	N/A	17.0	24.6	24.8
	Total	N/A	117.2	308.6	229.6
Soil moisture (%)	Max	40.0	36.1	45.0	N/A
	Min	22.9	16.0	12.9	N/A
Relative humidity (%)	Max	92.6	98.1	93.3	100
	Min	54.0	52.3	49.7	59.9

Wendover

In 2013 the lowest temperature (7.6°C) was recorded on 28 April and the highest on 4 September (22.1°C) (Figure 2). Maximum air temperature (22.6°C) was recorded on 1 August and the lowest (4.9°C) on 27 April. The monitoring period was relatively dry with no rain on 73% of days and only 117.2 mm in total. Most rain (17 mm) fell on 27 July. Soil moisture ranged between 16% and 36.1% and relative humidity between 52.3% and 98.1% (Figures 3 & 4, respectively). Soil moisture was not recorded beyond 27 August.

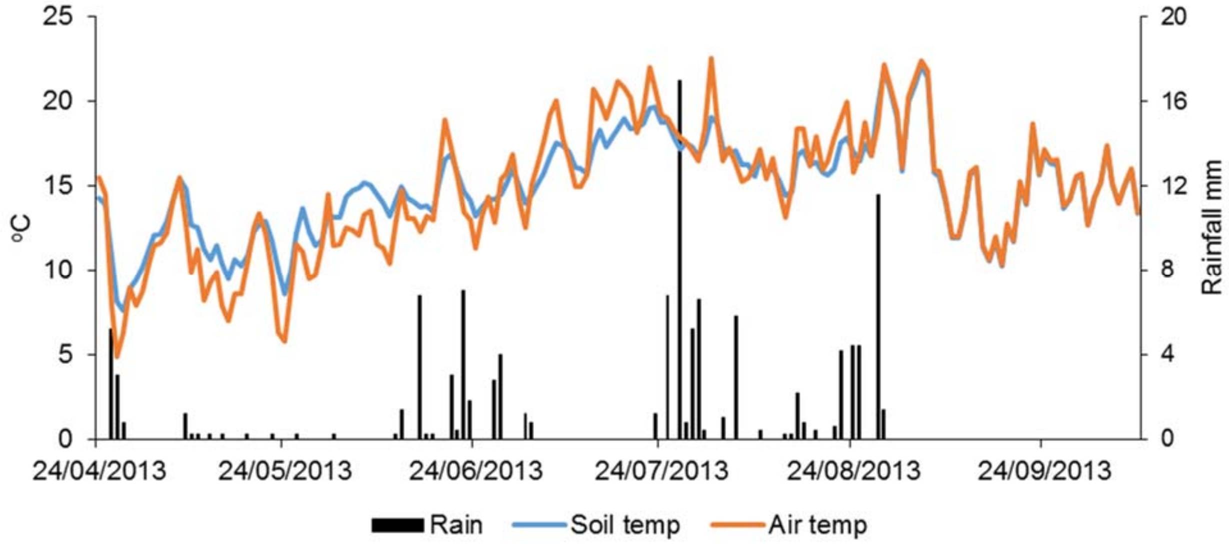

Figure 2. Air and soil temperature and rainfall at Wendover, Buckinghamshire from 21 April–9 October 2013.

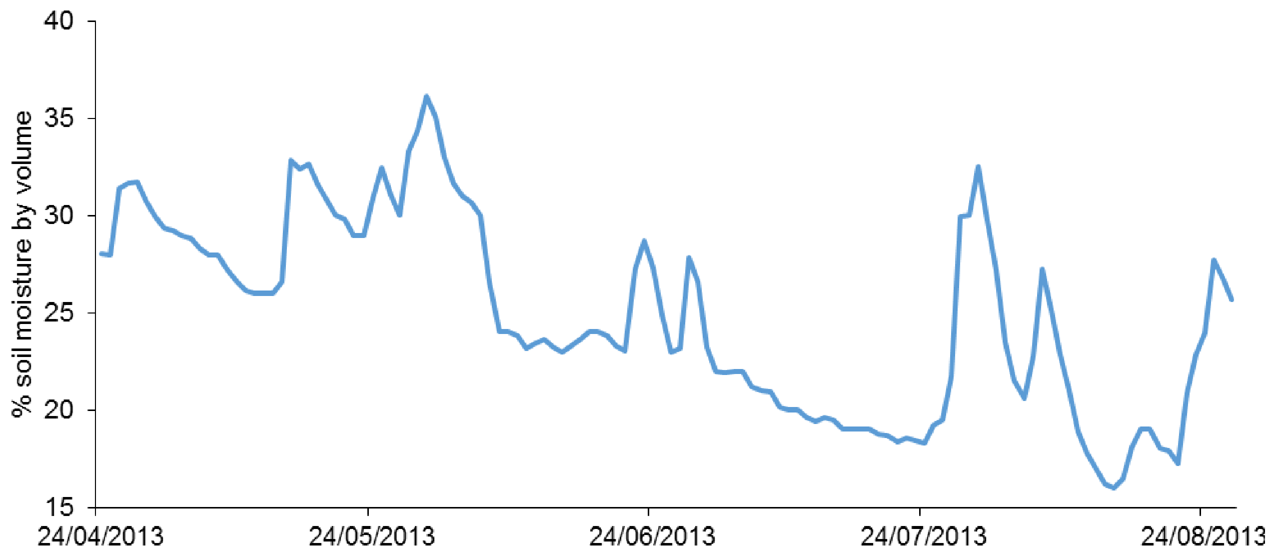

Figure 3. % soil moisture by volume at Wendover, Buckinghamshire from 24 April–27 August, 2013

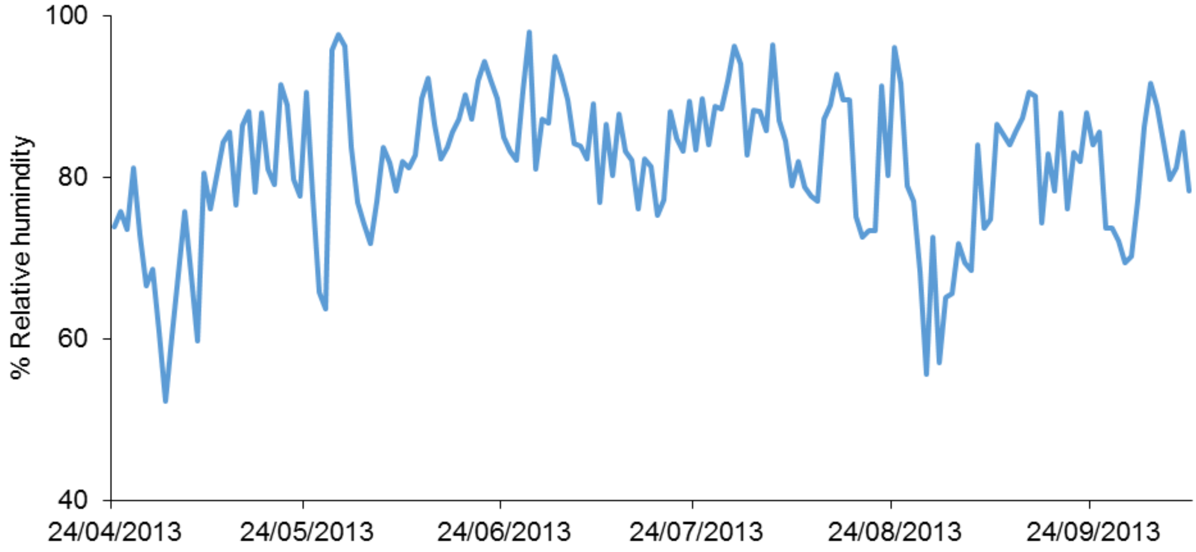

Figure 4. % relative humidity at Wendover, Buckinghamshire from 21 April–9 October 2013.

Soil and air temperatures in 2014 were similar to 2013. Soil temperature ranged from a minimum of 6.0°C on 26 March to a maximum of 20.6°C on 27 July. Air temperature was highest on 18 July (22.7°C) and lowest on 26 March (3.3°C, Figure 5). More rain fell than in 2013 with 308.6 mm in total. Rainfall between March and mid-August was more frequent than in 2013. Soil moisture ranged between 12.9% and 45% and was not recorded beyond 15 August (Figure 6). Relative humidity ranged between 49.7% and 93.3% (Figure 7).

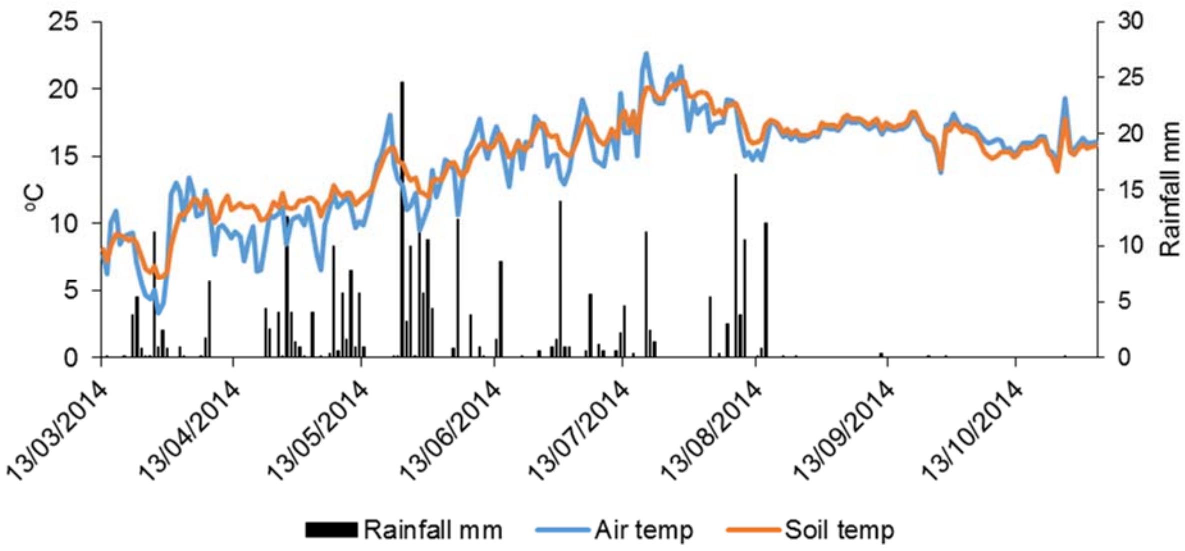

Figure 5. Air and soil temperature and rainfall at Wendover, Buckinghamshire from 13 March–31 October 2014.

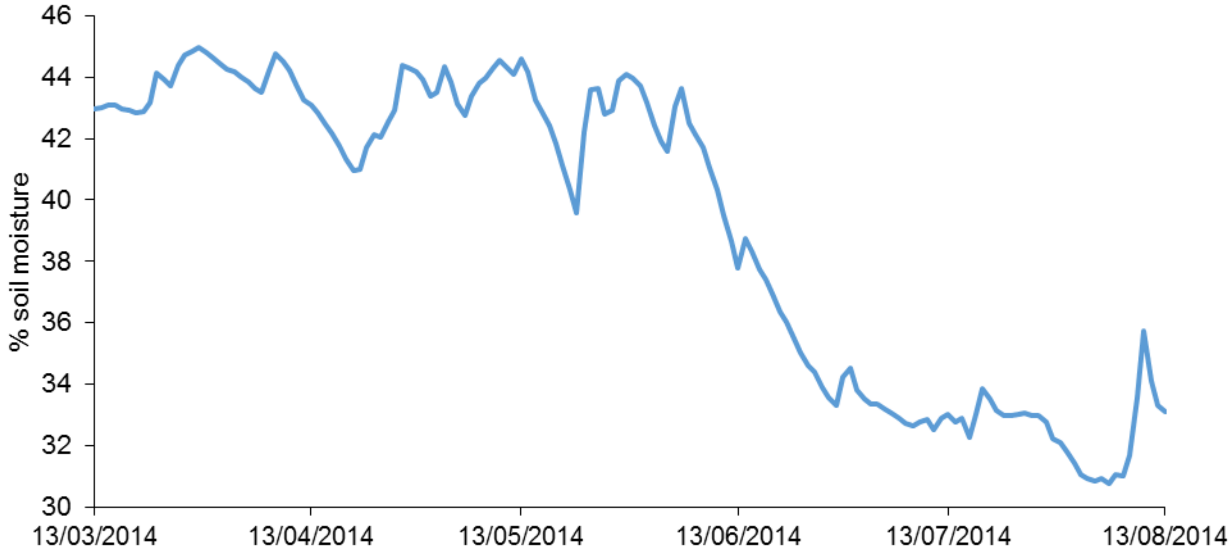

Figure 6. % soil moisture by volume at Wendover, Buckinghamshire from 13 March–15 August 2014.

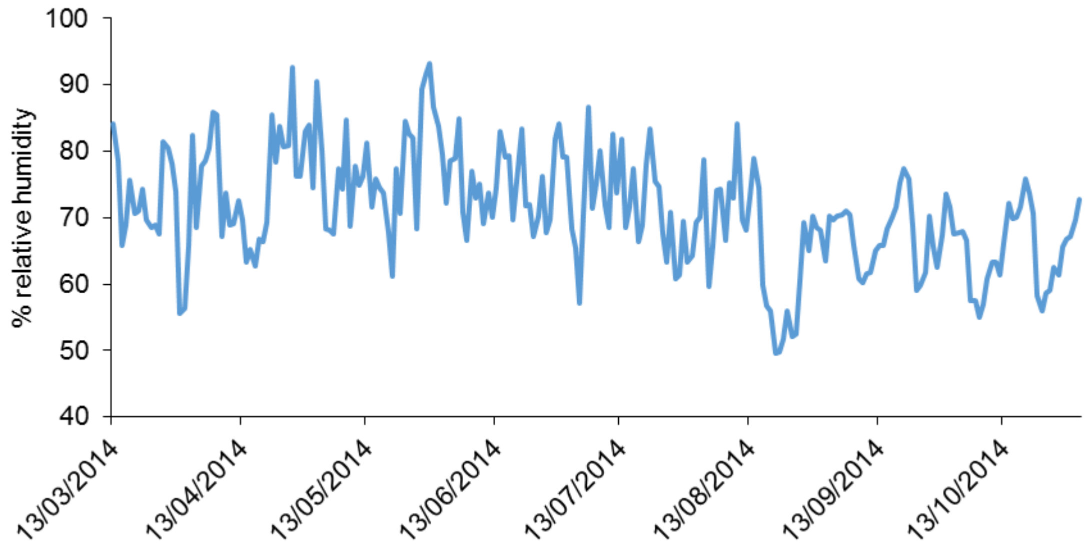

Figure 7. % relative humidity at Wendover, Buckinghamshire from 13 March–31 October 2014.

In 2015, a peak air temperature of 25.3°C was recorded on 10 September and a minimum air temperature of 5.8°C on 25 March (Figure 8). The probe for soil temperature only worked for 14 days and so data are not included. Peak rainfall (24.8 mm) was recorded on 24 July and there was no rain on 57% of days over the monitoring period and 229.6 mm in total. Relative humidity ranged between 59.9 and 100% (Figure 9).

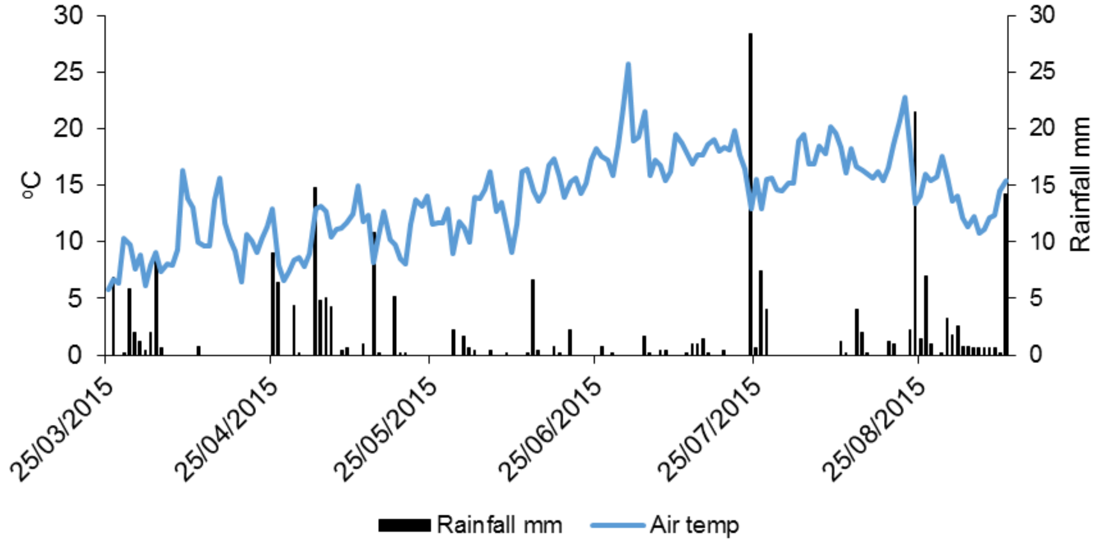

Figure 8. Air temperature and rainfall at Wendover, Buckinghamshire from 25 March–10 September 2015.

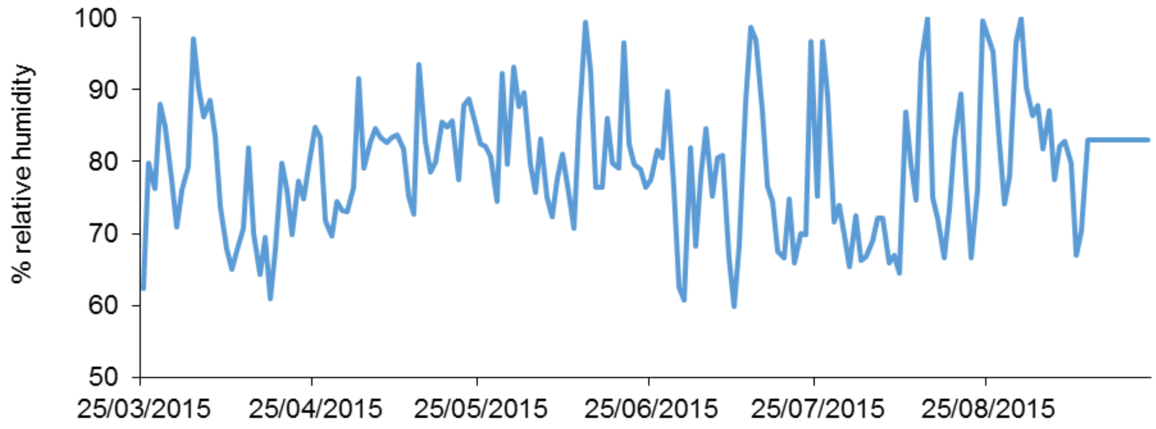

Figure 9. % relative humidity at Wendover, Buckinghamshire from 25 March–25 September 2015.

Sessay 2014

Temperatures were generally lower at Sessay than at Wendover (Figure 10). Peak air temperature of 18.5°C was recorded on 18 June and minimum temperature of 5.8°C on 19 April. Peak soil temperature was 15.9°C on 26 June and minimum soil temperature was 8.0°C on 19 April. Percentage soil moisture ranged between 22.9% and 40.0% (Figure 11). There were some breaks in the data in May and June. Relative humidity ranged between 54% and 92.6% (Figure 12).

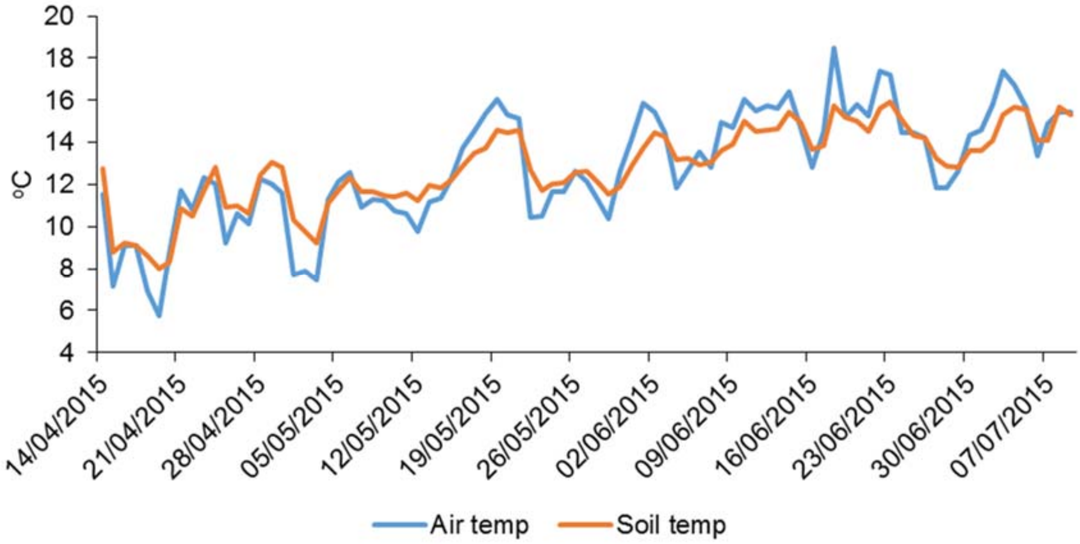

Figure 10. Air temperature at Sessay, North Yorkshire from 14 April–9 July 2014.

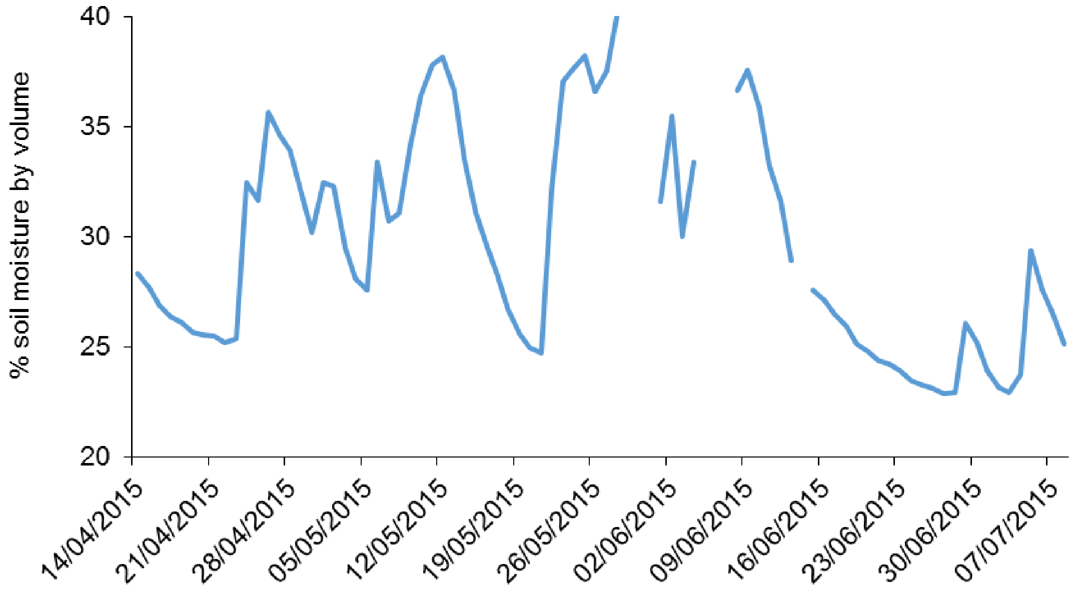

Figure 11. % soil moisture by volume at Sessay, North Yorkshire from 14 April–9 July 2014.

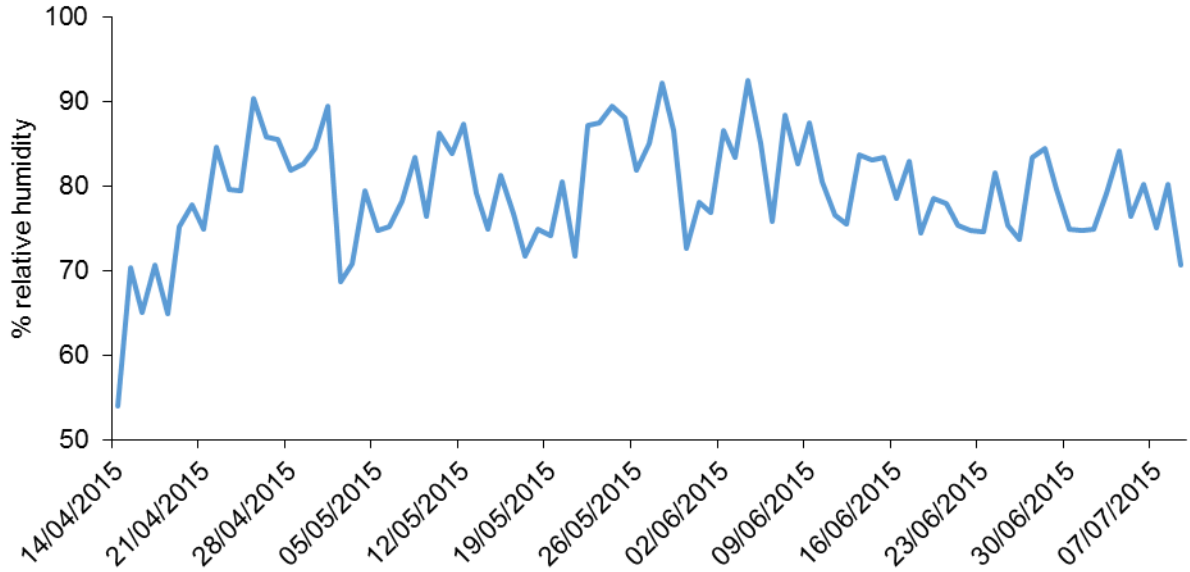

Figure 12. % relative humidity at Sessay, North Yorkshire from 14 April–9 July 2014.

4.1.2. Development of forecasting model for saddle gall midge (Collaboration with Charlotte Rowley at Harper Adams University)

The level of agreement between the site data and the final model predictions for saddle gall midge pupation and emergence are shown below (Table 8). Overall predictions from the both air and soil temperature models were earlier than recorded in the field at Wendover and later than recorded in the field at Sessay. The accuracy of the air temperature model for pupation at Wendover was six days and one to seven days for emergence and four days for emergence at Sessay The soil temperature model predicted pupation at Wendover to an accuracy of four days and emergence to an accuracy of two to seven days. Emergence at Sessay was predicted to be eight days later than was recorded in the field. The work has highlighted the potential to use models to predict pest pupation and emergence.

Table 8. Actual and predicted dates of pupation and emergence of saddle gall midge for ADAS sites based on a) air and b) soil temperatures.

a) Air temperatures

Site	Developmental stage	Actual Date	Predicted Date	Difference (days)
Wendover	Pupation 2014	22/04/2014	16/04/2014	6
	Emergence 2014	08/05/2014	01/05/2014	7
	Emergence 2015	13/05/2015	12/05/2015	1
Sessay	Emergence 2015	12/05/2015	16/05/2015	4

b) Soil temperatures

Site	Developmental stage	Actual Date	Predicted Date	Difference (days)
Wendover	Pupation 2014	22/04/2014	18/04/2014	4
	Emergence 2014	08/05/2014	06/05/2014	2
	Emergence 2015	13/05/2015	06/05/2015	7
Sessay	Emergence 2015	12/05/2015	20/05/2015	8

4.1.3. Soil sampling for developmental stages of saddle gall midge

It was originally intended to undertake soil sampling to monitor the development of saddle gall midge in 2013 and 2014 at Wendover in Buckinghamshire and in 2013, 2014 and 2015 at Sessay in North Yorkshire. Despite relatively high numbers of larvae in North Yorkshire in 2014 there was limited development to the pupal stages (see also page 25) so Wendover was monitored in each of the three project years and Sessay in 2013 and 2014 only.

Saddle gall midge larvae, neonate pupae and sclerotised pupae were all recovered by soil sampling and the stages photographed (Figures 13–15). The neonate pupa is the stage that follows the larva and the sclerotised pupae precedes adult emergence.

Figure 13. Saddle gall midge larvae

Figure 14. Neonate pupa of saddle gall midge

Figure 15. Sclerotised pupa of saddle gall midge

The results of soil monitoring at both Wendover and Sessay are summarised in Figures 16 to 20.

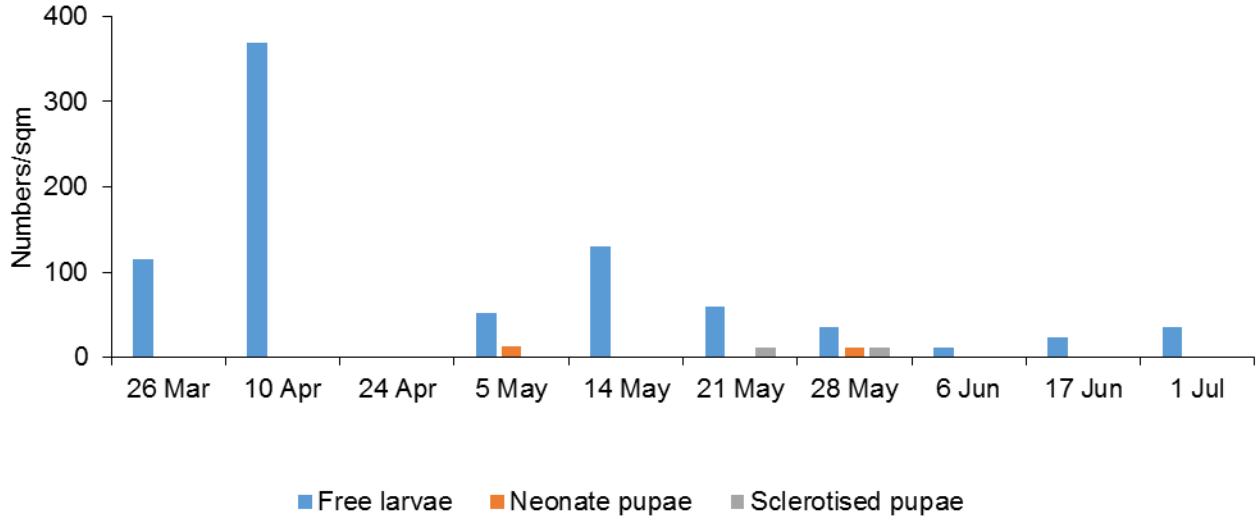

Figure 16. Saddle gall midge developmental stages in soil (numbers/m^2) over the monitoring period at Wendover in 2013.

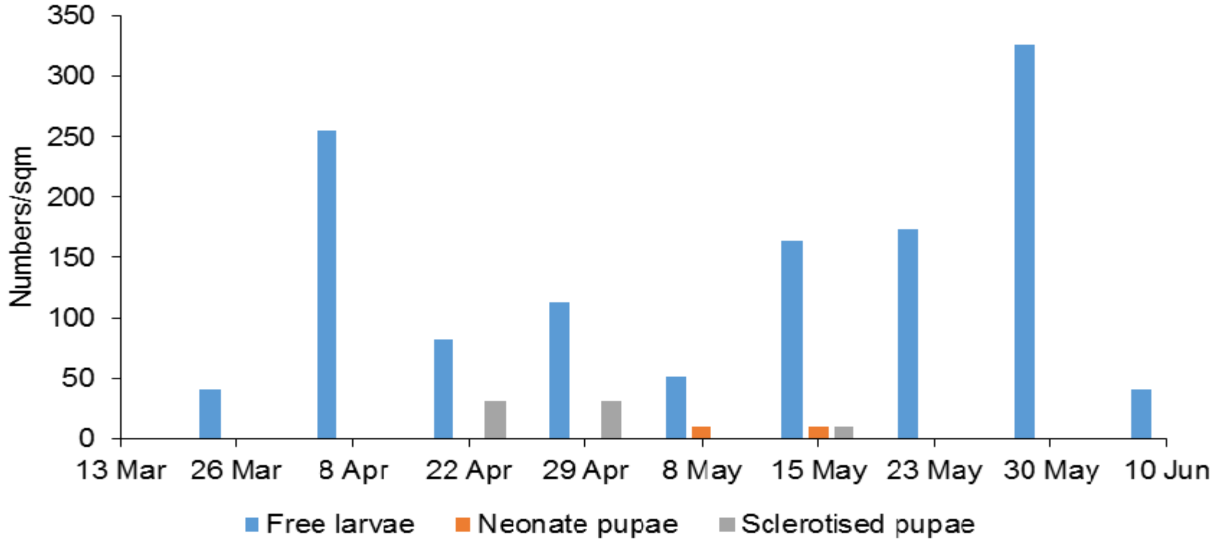

Figure 17. Saddle gall midge developmental stages in soil (numbers/m^2) over the monitoring period at Wendover in 2014.

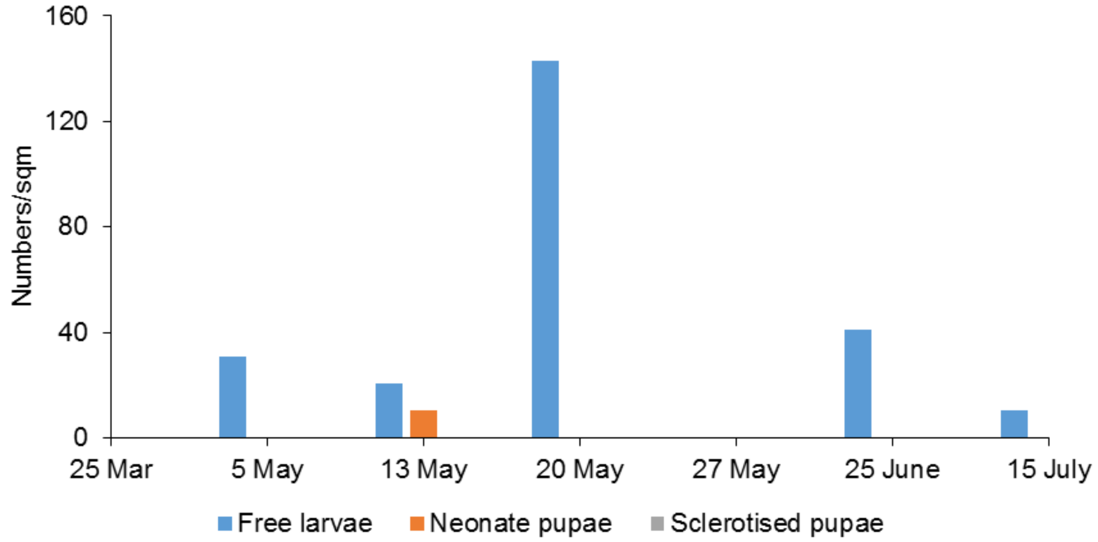

Figure 18. Saddle gall midge developmental stages in soil (numbers/m^2) over the monitoring period at Wendover in 2015.

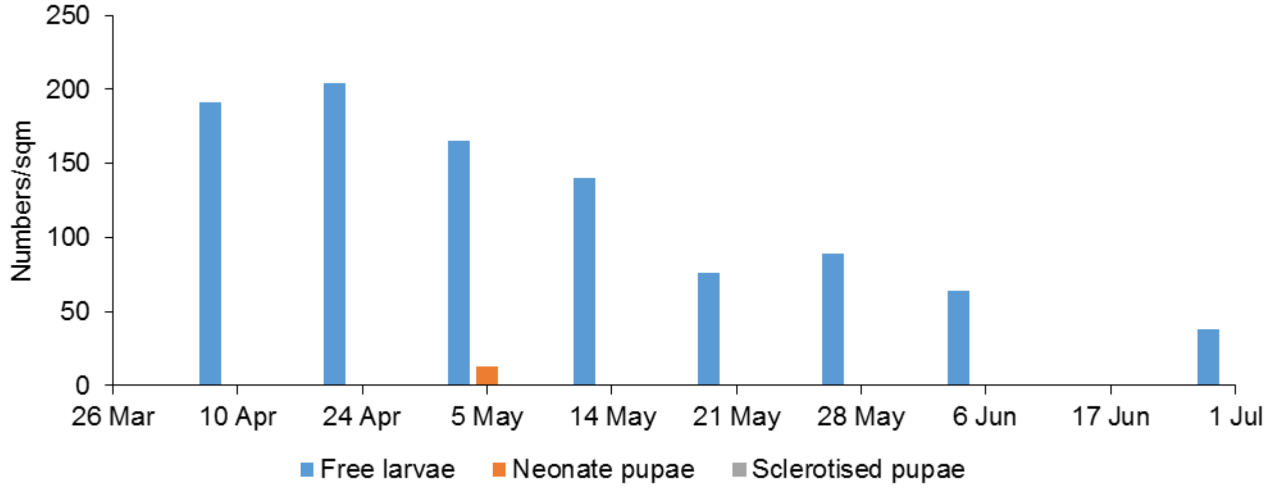

Figure 19. Saddle gall midge developmental stages in soil (numbers/m^2) over the monitoring period at Sessay North Yorkshire in 2013.

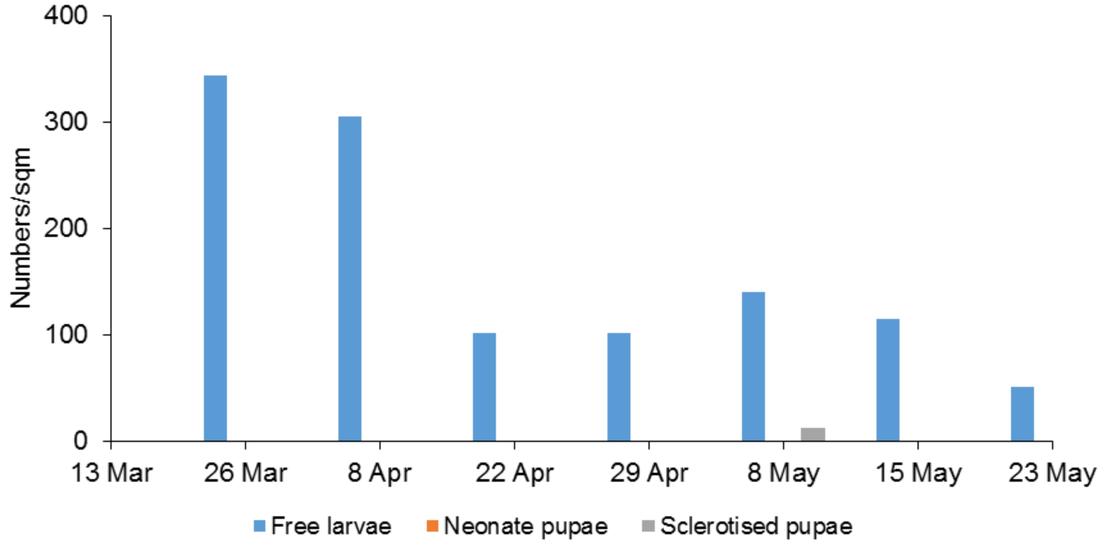

Figure 20. Saddle gall midge developmental stages in soil (numbers/m²) over the monitoring period at and Sessay North Yorkshire in 2014.

At both sites saddle gall midge larvae were the easiest developmental stage to find. There were few neonate or sclerotised pupae recovered throughout three years of monitoring. It is unclear whether this is due to significant mortality between the larval and pupal stages or whether the pupal stages are inherently more difficult to extract or recognise in extracted material.

At Wendover the maximum number of larvae were recovered on 10 April in 2013 (369/m^2), 30 May 2014 (327/m^2) and 20 May in 2015 (143/m^2). Maximum numbers of larvae declined by 56% between 2014 and 2015. Numbers of neonate pupae never exceeded 13/m^2 and sclerotised pupae never exceeded 31/m^2 throughout the three years of the project. Neonate pupae were recovered on 5 and 28 May in 2013 and sclerotised pupae on 21 and 28 May. In 2014 neonate pupae were found on 8 and 15 May and sclerotised pupae on 22 and 29 April. Over three years of monitoring pupation was never recorded before 22 April

At Sessay maximum numbers of larvae were recorded on 24 April 2013 (204/m^2) and on 13 March 2014 (369/m^2). Neonate pupae were recovered on 5 May in 2013 (13/m^2) but no sclerotised pupae were found. In 2014 there were no neonate pupae recovered but 13 sclerotised pupae/m^2 on 8 May. At Sessay pupation was in early May in both 2013 (5 May) and 2014 (8 May)

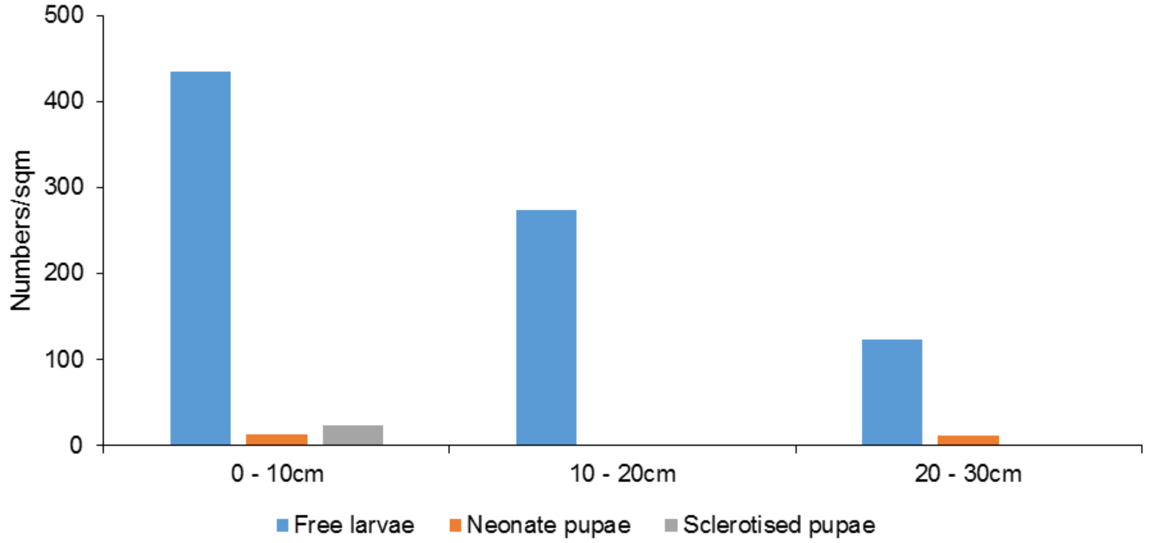

Figure 21. Saddle gall midge developmental stages in soil (numbers/m^2) at three soil depths at Wendover in 2013.

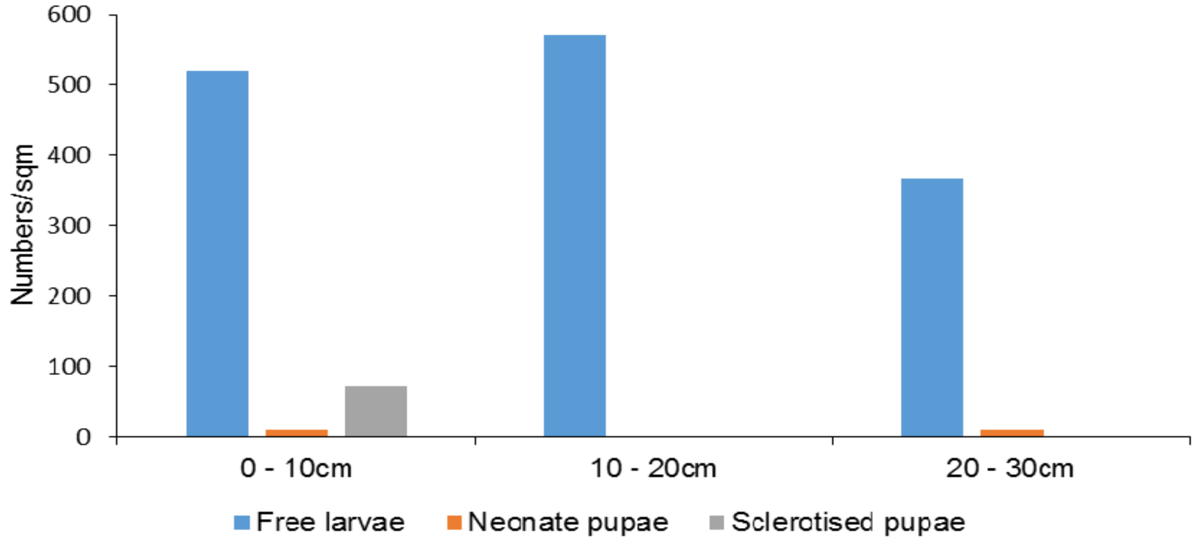

Figure 22. Saddle gall midge developmental stages in soil (numbers/m^2) at three soil depths at Wendover in 2014.

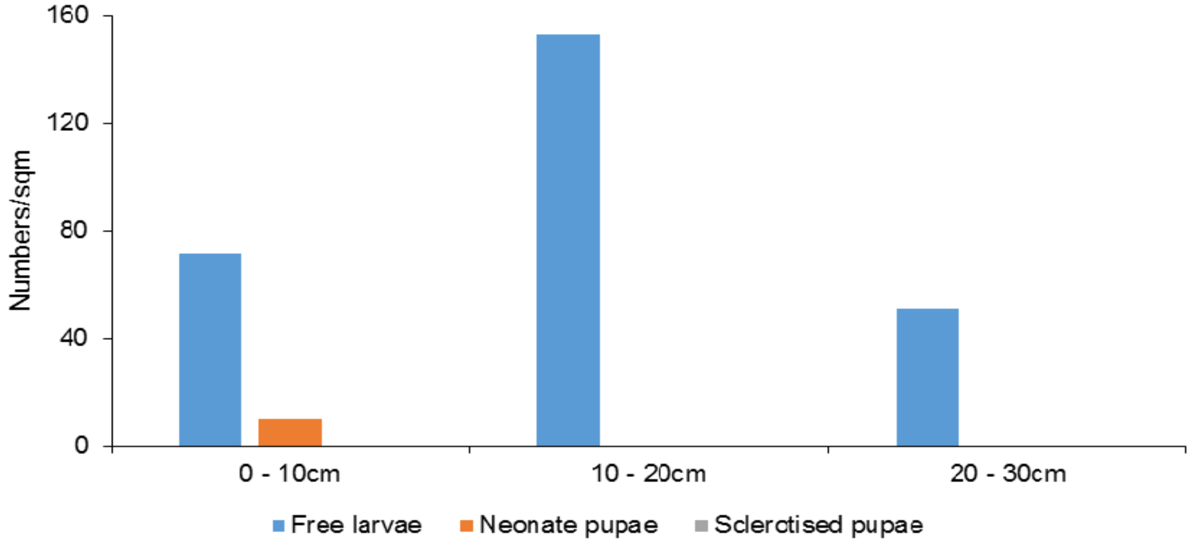

Figure 23. Saddle gall midge developmental stages in soil (numbers/m^2) at three soil depths at Wendover in 2015.

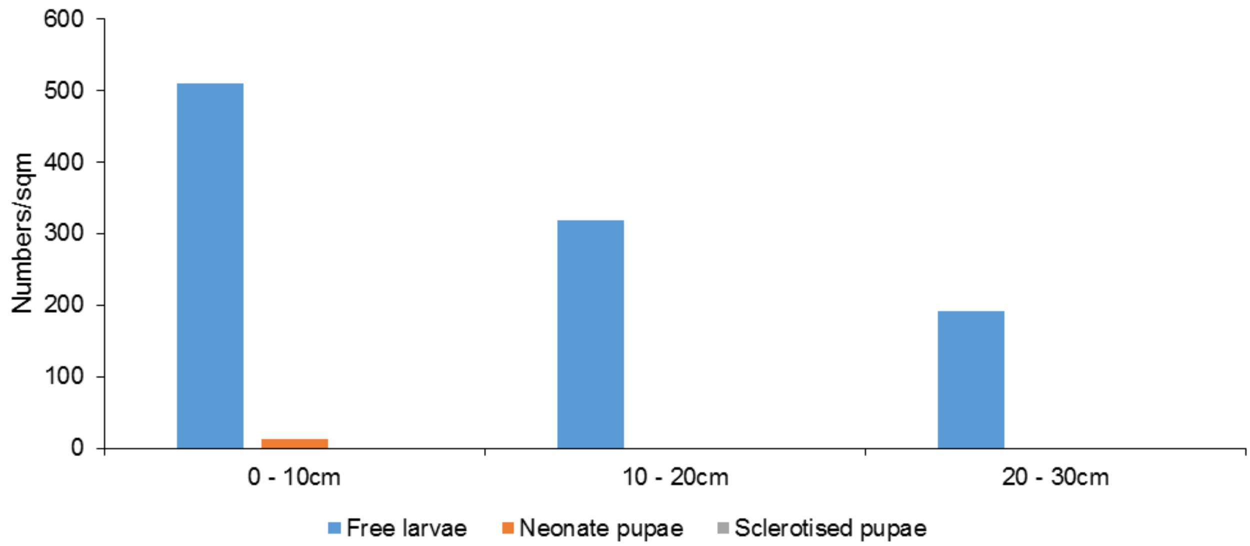

Figure 24. Saddle gall midge developmental stages in soil (numbers/m^2) at three soil depths at Sessay in 2013.

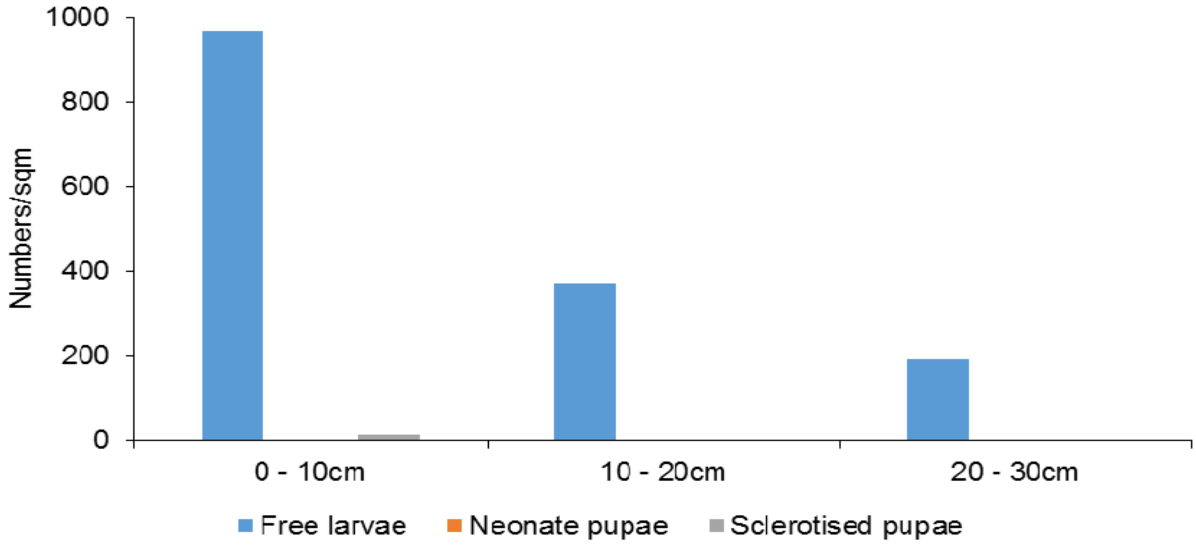

Figure 25. Saddle gall midge developmental stages in soil (numbers/m^2) at three soil depths at Sessay in 2014.

Larvae at Wendover were most frequently recorded at a depth of 0–10 cm in both 2013 and 2014 but at 10–20 cm in 2015. At Sessay most free larvae were found at 0–10 cm in both 2014 and 2015. Over all sites on average 78% of free larvae were recovered from a soil depth of 0–20 cm (Figures 21-25)

Pupae were recovered from all soil depths but because of the low numbers found it is difficult to comment on their general distribution through the soil profile.

4.1.4. Larval parasitism at Sessay, North Yorkshire in 2013

Saddle gall midge larvae recovered from Sessay in 2013 appeared discoloured in comparison with those extracted from the Wendover site. Closer examination showed that the discoloured larvae had been infected by a parasitic fungus. A comparison of a parasitised and a healthy larva is shown in Figure 26.

Samples of the infected larvae were sent to Dr Dave Chandler at Warwick Crop Centre. The parasitic fungus was isolated and identified as *Lecanicillium* sp. A culture of the fungus is being held by Warwick Crop Centre for potential future research.

Figure 26. Healthy (right) and parasitised (left) saddle gall midge larvae extracted from soil at Sessay North Yorkshire, 2013.

4.1.5. Monitoring saddle gall midge emergence

Water traps, yellow sticky traps and emergence traps were compared as a method of monitoring saddle gall midge emergence at Wendover, Buckinghamshire in all three years of the project and at Sessay in North Yorkshire in 2014 only. It was intended to monitor at Sessay in 2013 but the presence of the parasitic fungus meant that very few larvae developed into the pupal stage.

Catches differed between traps on the first four trapping occasions at Wendover in 2013 and on the first two trapping occasions at the same site in 2014 (Table 9). On these occasions yellow water traps had the highest trap catch. Overall there was a trend to find most or equal most adults in yellow water traps on 17 out of 18 trapping occasions. Catches at Sessay in 2014 and Wendover in 2015 were very low and never exceeded one midge/trap/day. At Wendover on 13 May 2015 very strong winds blew all the sticky traps from their cane supports so no catch data was available for this date

Evaluation of saddle gall midge pheromone traps (Collaboration with Charlotte Rowley at Harper Adams University)

Pheromone traps (Figure 27) were very effective at catching saddle gall midge adults at both Wendover, Buckinghamshire and Sessay, North Yorkshire. Catches were so high that numbers of midges were only counted on 20% of the sticky inserts and this figure multiplied by five to give the total catch (Table 10). At Wendover the highest catch was 217/trap/day and at Sessay it was

300/trap/day. The catches in pheromone traps were significantly higher than those with any method of monitoring adult midge emergence.

Table 9. Mean catches of saddle gall midge adults (number/trap/day) in yellow sticky, yellow water and emergence traps at Wendover from 2013 to 2015 and Sessay in 2013 and 2014.

Site	Year	Date	Trap type			Probability	SED (DF)
			Yellow sticky	Yellow water	Emergence		
Wendover	2013	21 May	0	1.5	0.2	P<0.01	0.42 (18)
		28 May	0.4	5.4	0.5	P<0.001	0.85 (18)
		6 June	0.1	1.1	0.1	P<0.05	0.42 (18)
		17 June	0	7.0	0.2	P<0.001	0.96 (18)
		1 July	0.2	0.2	0	NS	0.14 (18)
	2014	8 May	0.7	4.7	0.4	P<0.001	1.09 (18)
		15 May	0.5	2.5	1.3	P<0.05	0.75 (18)
		23 May	0.7	3.3	2.8	NS	1.25 (18)
		30 May	0.6	2.5	2.0	NS	0.98 (18)
		10 June	0.1	0.3	0.3	NS	0.22 (18)
	2015	13 May	N/A	0.7	0.2	NS	0.34 (9)
		21 May	0.2	0.5	0.2	NS	0.22 (17)
		27 May	0.2	0.5	0.2	NS	0.25 (17)
Sessay	2014	11 June	0	0.6	0	NS	0.33 (18)
		18 June	0.1	0.2	0.1	NS	0.17 (18)
		26 June	0.2	0.4	0.1	NS	0.22 (18)
		2 July	0.3	0.2	0.1	NS	0.19 (18)
		8 July	0	0.2	0	NS	0.11 (18)

Table 10. Catches of adult saddle gall midge in pheromone traps at Wendover, Buckinghamshire and Sessay north Yorkshire in 2015.

Site	Date	Trap 1		Trap 2	
		Total catch	No/trap/day	Total catch	No/trap/day
Wendover	13 May	1738	217	1688	211
Sessay	12 May	2100	300	1260	180
	19 May	420	60	840	120
	26 May	300	43	630	90
	2 June	336	48	420	60

Figure 27. Saddle gall midge pheromone traps showing, lure and sticky insert covered with saddle gall midge adults.

4.2. Impact of saddle gall midge on crop yield

The numbers of grains per ear, individual grain weight and grain yield per ear were compared between tillers of plants infested by saddle gall midge and uninfested tillers at seven sites (six wheat, one spring barley). Up to four infested tillers or uninfested tillers were compared per plant (Table 11). The straw weight per tiller, chaff weight per tiller and total tiller yield were also compared at Wendover in 2014 and 2015 and at Boxworth in 2014. In total there were 70 comparisons made between infested and uninfested tillers across all yield parameters and significant differences were only detected on 23 occasions (33%). Where significant differences were detected the value for the uninfested tiller was highest on 11 occasions (48%) and the value for the infested tiller was highest on 12 occasions (52%). These results suggest that pest levels were below those normally expected to be damaging and did not necessarily result in a loss of yield or grain number at the sites studied. It is also likely that in some instances crops were able to compensate for pest attack.

Regression analysis was used to investigate relationships between the total yield of grain per ear and gall number for up to three tillers at a number of sites (Table 12). Significant correlations were only recorded on four of 14 occasions and the percentage variance accounted for never exceeded 27.1%.

Table 11. Comparison of grain number, weight per grain (g), grain yield per ear (g), straw yield (g), chaff yield (g) and total yield (g) of tillers infested with saddle gall midge or uninfested tillers. (Probability values are for a Students 'T' test comparing infested and uninfested tillers)

Site	**% infested tillers & galls/tiller**	**Tiller 1**		**Tiller 2**		**Tiller 3**		**Tiller 4**	
		Uninfested	**Infested**	**Uninfested**	**Infested**	**Uninfested**	**Infested**	**Uninfested**	**Infested**
Wendover 2013, W wheat	15.2 & 0.6								
Grain number		39.3	36.7	31.5	35.2	35.6	39.7		
Probability (P)		<0.05		0.096		0.242			
SED (DF)		1.22 (198)		2.23 (115)		3.47 (55)			
Weight/grain		0.041	0.044	0.041	0.061	0.039	0.044		
Probability (P)		0.001		0.143		<0.01			
SED (DF)		0.0009 (198)		0.0136 (61.6)		0.0019 (55)			
Grain yield/ear		1.64	1.62	1.31	2.03	1.43	1.79		
Probability (P)		0.824		0.134		0.052			
SED (DF)		0.068 (198)		0.471 (64.9)		0.180 (55)			
Wendover 2014, W wheat	12.3 & 0.4								
Grain number		66.3	60.3	52.1	65.6	51.0	62.1		
Probability (P)		0.275		<0.05		0.370			
SED (DF)		5.45 (46)		6.15 (25)		12.0 (14)			
Weight/grain		0.047	0.048	0.043	0.048	0.040	0.047		
Probability (P)		0.571		0.139		0.233			
SED (DF)		0.0021 (46)		0.0034 (25)		0.0057 (14)			
Site		**Tiller 1**		**Tiller 2**		**Tiller 3**		**Tiller 4**	

	% infested tillers & galls/tiller	Uninfested	Infested	Uninfested	Infested	Uninfested	Infested	Uninfested	Infested
Wendover 2014, W wheat	12.3 & 0.4								
Grain yield/ear		3.10	3.00	2.28	3.23	2.26	3.08		
Probability (P)		0.738		<0.05		0.294			
SED (DF)		0.304(46)		0.407 (25)		0.756 (14)			
Straw weight/tiller		1.47	1.32	1.12	1.38	1.10	1.27		
Probability (P)		0.251		0.083		0.549			
SED (DF)		0.024 (46)		0.142 (25)		0.278 (14)			
Chaff weight/tiller		0.68	0.63	0.54	0.67	0.58	0.65		
Probability (P)		0.396		0.070		0.577			
SED (DF)		0.063 (46)		0.063 (25)		0.128 (14)			
Total tiller weight		5.24	4.94	3.95	5.28	3.93	5.00		
Probability (P)		0.529		<0.05		0.367			
SED (DF)		0.475 (46)		0.598 (25)		1.146 (14)			
Sessay 2013 W wheat									
Grain number		41.1	30.9	39.3	46.6	42.2	36.8	43.4	36.2
Probability (P)		0.118		0.218		0.455		0.077	
SED (DF)		6.24 (20)		5.71 (20)		7.07 (18)		3.74 (12)	
Weight/grain		0.053	0.052	0.056	0.056	0.055	0.049	0.057	0.055
Probability (P)		0.662		0.924		0.150		0.470	
SED (DF)		0.0026 (20)		0.0020 (20)		0.0040 (12.5)		0.0020 (12)	

Site	% infested tillers & galls/tiller	Tiller 1		Tiller 2		Tiller 3		Tiller 4	
		Uninfested	**Infested**	**Uninfested**	**Infested**	**Uninfested**	**Infested**	**Uninfested**	**Infested**
Sessay 2013 W wheat									
Grain yield/ear		2.15	1.65	2.19	2.62	2.30	1.93	2.48	2.00
Probability (P)		0.176		0.221		0.372		0.074	
SED (DF)		0.356 (20)		0.338 (20)		0.404 (18)		0.244 (12)	
Boxworth 2014 W wheat									
Grain number		51.4	58.9	37.6	59.0				
Probability (P)		0.062		<0.01					
SED (DF)		3.92 (48)		6.80 (28)					
Weight/grain		0.055	0.055	0.051	0.055				
Probability (P)		0.887		0.171					
SED (DF)		0.0013 (48)		0.0027 (28)					
Grain yield/ear		2.82	3.25	2.03	3.26				
Probability (P)		0.090		<0.01					
SED (DF)		0.246 (48)		0.385 (28)					
Straw weight/tiller		1.42	1.54	1.14	1.52				
Probability (P)		0.325		0.01					
SED (DF)		0.115 (41.3)		0.138 (28)					
Chaff weight/tiller		0.44	0.49	0.32	0.49				
Probability (P)		0.229		<0.01					
SED (DF)		0.035 (48)		0.053 (28)					

Site	**% infested tillers & galls/tiller**	**Tiller 1**		**Tiller 2**		**Tiller 3**		**Tiller 4**	
		Uninfested	**Infested**	**Uninfested**	**Infested**	**Uninfested**	**Infested**	**Uninfested**	**Infested**
Boxworth 2014 W wheat									
Total tiller weight		4.69	5.27	3.49	5.26				
Probability (P)		0.130		<0.01					
SED (DF)		0.379 (48)		0.552 (28)					
Great Saxham 2013 W wheat									
Grain number		54.5	46.3	47.0	54.4	51.6	57.5		
Probability (P)		<0.001		<0.01		0.068			
SED (DF)		2.19 (185.9)		2.34 (191)		3.18 (109)			
Weight/grain		0.042	0.043	0.041	0.042	0.040	0.045		
Probability (P)		<0.001		0.181		<0.001			
SED (DF)		0.0007 (180.7)		0.0009 (180.8)		0.0009 (109)			
Grain yield/ear		2.26	1.99	1.91	2.31	2.08	2.55		
Probability (P)		<0.01		<0.001		<0.001			
SED (DF)		0.102 (180.7)		0.110 (190)		0.141 (109)			
Wendover 2015 W wheat	2.0 & 0.1								
Grain number		47.7	50.0	42.7	43.0	44.8	35.1		
Probability (P)		0.415		0.942		<0.05			
SED (DF)		2.77 (96)		3.83 (58)		3.72 (29)			

Site	**% infested tillers & galls/tiller**	**Tiller 1**		**Tiller 2**		**Tiller 3**		**Tiller 4**	
		Uninfested	**Infested**	**Uninfested**	**Infested**	**Uninfested**	**Infested**	**Uninfested**	**Infested**
Wendover 2015 W wheat	2.0 & 0.1								
Weight/grain		0.040	0.041	0.040	0.041	0.038	0.039		
Probability (P)		0.489		0.358		0.514			
SED (DF)		0.0015 (96)		0.0016 (58)		0.0019 (29)			
Grain yield/ear		1.92	2.06	1.71	1.79	1.74	1.37		
Probability (P)		0.349		0.652		<0.05			
SED (DF)		0.146 (96)		0.184 (58)		0.158 (28.5)			
Straw weight/tiller		1.51	1.55	1.34	1.35	1.39	1.09		
Probability (P)		0.653		0.880		<0.05			
SED (DF)		0.0903 (96)		0.122 (58)		0.124 (29)			
Chaff weight/tiller		0.45	0.48	0.43	0.41	0.40	0.33		
Probability (P)		0.306		0.735		0.057			
SED (DF)		0.030 (96)		0.043 (58)		0.037 (28)			
Total tiller weight		3.87	4.08	3.47	3.56	3.51	2.80		
Probability (P)		0.417		0.794		<0.05			
SED (DF)		0.256 (96)		0.333 (58)		0.326 (29)			
Kelso 2015 S barley									
Grain number		22.8	18.0						
Probability (P)		0.080							
SED (DF)		2.50 (10.7)							

Site	% infested tillers & galls/tiller	Tiller 1		Tiller 2		Tiller 3		Tiller 4	
		Uninfested	**Infested**	**Uninfested**	**Infested**	**Uninfested**	**Infested**	**Uninfested**	**Infested**
Weight/grain		0.043	0.029						
Probability (P)		<0.05							
SED (DF)		0.0049 (19)							

Table 12. Correlations between grain yield per ear (g (Y)) and number of galls per tiller (X)

Site & year	Year	Tiller number	Equation	% variance accounted for	Probability
Boxworth	2014	1	N/A	N/A	0.639
		2	N/A	N/A	0.956
Great Saxham	2013	1	N/A	N/A	0.297
		2	Y = 0.02 galls + 1.96	4.6	<0.01
		3	N/A	2.0	0.076
Kelso	2015	1	Y = -0.17 galls + 0.99	27.1	<0.01
Sessay	2013	1	N/A	9.1	0.094
Wendover	2013	1	N/A	N/A	0.342
		2	N/A	N/A	0.533
		3	N/A	N/A	0.716
Wendover	2014	1	Y = -0.12 galls + 3.21	7.9	<0.05
		2	N/A	0.6	0.294
		3	N/A	N/A	0.800
Wendover	2015	1	N/A	N/A	0.420
		2	N/A	N/A	0.255
		3	N/A	N/A	0.460

4.3. Chemical control options for saddle gall midge

A total of four field experiments were conducted over the three years of the project. Three of these were at Wendover, Buckinghamshire in 2013, 2014 and 2015 and one was at Royston, Cambridgeshire in 2015. The experiments at Wendover in 2013 and 2014 used the treatment list described at Table 5 and the experiments at Wendover and Royston in 2015 used the treatment list described at Table 6. The 2015 experiments included an evaluation of programmes of lamda-cyhalothrin not included in 2013 and 2014.

4.3.1. Wendover 2013 and 2014

The % tillers infested differed significantly between insecticide timings at Wendover in 2014 (P<0.001, Table 13)).

Table 13. Mean % tillers infested with saddle gall midge larvae at Wendover in 2013 and 2014

Wendover 2013						
Product	Control	**Insecticide timing**				**Mean**
		1st adults	T1 + 7-10 days	1st eggs	1st Larvae	
	17.6					
Chlorpyrifos		22.2	11.1	11.9	19.0	16.1
Lamda-cyhalothrin		3.8	4.3	14.5	24.7	11.8
Thiacloprid		13.8	21.2	12.2	21.9	17.3
Mean		13.3	12.2	12.9	21.9	
SED for comparison of product means (36DF) = 3.46						
SED for comparison of timing means (36DF) = 3.99						
SED for comparisons within the body of the table (36DF) = 6.92						
Wendover 2014						
Product	Control	**Insecticide timing**				**Mean**
		1st adults	T1 + 7-10 days	1st eggs	1st Larvae	
	11.9					
Chlorpyrifos		4.8	3.7	14.4	32.3	13.8
Lamda-cyhalothrin		2.5	12.9	11.0	13.2	9.9
Thiacloprid		4.4	11.9	10.0	26.7	13.2
Mean		3.9	9.5	11.8	24.0	
SED for comparison of product means (36DF) = 4.11						
SED for comparison of timing means (36DF) = 4.74						
SED for comparisons within the body of the table (36DF) = 8.22						

Insecticides sprays applied to coincide with the first sighting of saddle gall midge adults, 7 days later or at the first sighting of midge eggs had a lower level of tiller infestation than sprays targeted at larvae ($P<0.05$). In 2013 at Wendover there was a trend for sprays targeted at adults or eggs to have a lower level of tiller infestation than those targeted at larvae but differences were not statistically significant. There was no significant difference between products and no interaction between product and spray timing.

There was a significant difference in the % plants infested by midge larvae between insecticide timings at Wendover in both 2013 ($P<0.05$, Table 14) and 2014 ($P<0.001$). In both years sprays targeted at adult midges or eggs were significantly better than those targeted at larvae ($P<0.05$) and in 2014 a spray applied when adults were first seen was better than one applied at the first appearance of eggs ($P<0.05$).

Table 14. Mean % plants infested with saddle gall midge larvae at Wendover in 2013 and 2014

Wendover 2013						
Product	Control	**Insecticide timing**				**Mean**
		1st adults	T1 + 7–10 days	1st eggs	1st Larvae	
	29.0					
Chlorpyrifos		32.0	18.0	19.0	30.0	24.8
Lamda-cyhalothrin		8.0	7.0	22.0	39.0	19.0
Thiacloprid		22.0	34.0	17.0	35.0	27.0
Mean		20.7	19.7	19.3	34.7	
SED for comparison of product means (36DF) = 5.05						
SED for comparison of timing means (36DF) = 5.83						
SED for comparisons within the body of the table (36DF) = 10.09						
Wendover 2014						
Product	Control	**Insecticide timing**				**Mean**
		1st adults	T1 + 7-10 days	1st eggs	1st Larvae	
	32.5					
Chlorpyrifos		10.0	10.0	27.5	45.0	23.1
Lamda-cyhalothrin		2.5	30.0	25.0	27.5	21.3
Thiacloprid		12.5	20.0	15.0	45.0	23.1
Mean		8.3	20.0	22.5	39.2	
SED for comparison of product means (36DF) = 5.82						
SED for comparison of timing means (36DF) = 6.73						
SED for comparisons within the body of the table (36DF) = 11.65						

There was no difference in % infested plants between insecticide products and no interaction between product and spray timing. The number of galls/tiller differed significantly between insecticide timings at Wendover in both 2013 and 2014 ($P<0.05$ and $P<0.001$, respectively, Table 15). In both years all insecticide timings targeted at adult midges or their eggs significantly reduced the number of galls/tiller in comparison with sprays targeted at the larvae ($P<0.05$). Insecticide products did not differ significantly and there was no interaction between products and spray timing.

Table 15. Mean numbers of saddle gall midge galls/tiller at Wendover in 2013 and 2014

<table>
<tr><td colspan="7">Wendover 2013</td></tr>
<tr><td rowspan="3">Product</td><td rowspan="2">Control</td><td colspan="4">Insecticide timing</td><td rowspan="2">Mean</td></tr>
<tr><td>1st adults</td><td>T1 + 7–10 days</td><td>1st eggs</td><td>1st Larvae</td></tr>
<tr><td>0.61</td><td colspan="4"></td><td></td></tr>
<tr><td>Chlorpyrifos</td><td rowspan="4"></td><td>0.94</td><td>0.45</td><td>0.33</td><td>0.94</td><td>0.66</td></tr>
<tr><td>Lamda-cyhalothrin</td><td>0.12</td><td>0.12</td><td>0.43</td><td>0.93</td><td>0.40</td></tr>
<tr><td>Thiacloprid</td><td>0.58</td><td>0.88</td><td>0.36</td><td>0.81</td><td>0.66</td></tr>
<tr><td>Mean</td><td>0.55</td><td>0.48</td><td>0.37</td><td>0.89</td><td></td></tr>
<tr><td colspan="7">SED for comparison of product means (36DF) = 0.144</td></tr>
<tr><td colspan="7">SED for comparison of timing means (36DF) = 0.166</td></tr>
<tr><td colspan="7">SED for comparisons within the body of the table (36DF) = 0.288</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="7">Wendover 2014</td></tr>
<tr><td rowspan="3">Product</td><td rowspan="2">Control</td><td colspan="4">Insecticide timing</td><td rowspan="2">Mean</td></tr>
<tr><td>1st adults</td><td>T1 + 7-10 days</td><td>1st eggs</td><td>1st Larvae</td></tr>
<tr><td>0.039</td><td colspan="4"></td><td></td></tr>
<tr><td>Chlorpyrifos</td><td rowspan="4"></td><td>0.15</td><td>0.18</td><td>0.45</td><td>0.82</td><td>0.40</td></tr>
<tr><td>Lamda-cyhalothrin</td><td>0.03</td><td>0.22</td><td>0.33</td><td>0.66</td><td>0.31</td></tr>
<tr><td>Thiacloprid</td><td>0.08</td><td>0.37</td><td>0.30</td><td>0.90</td><td>0.41</td></tr>
<tr><td>Mean</td><td>0.08</td><td>0.26</td><td>0.36</td><td>0.79</td><td></td></tr>
<tr><td colspan="7">SED for comparison of product means (36DF) = 0.142</td></tr>
<tr><td colspan="7">SED for comparison of timing means (36DF) = 0.164</td></tr>
<tr><td colspan="7">SED for comparisons within the body of the table (36DF) = 0.285</td></tr>
</table>

There was no significant difference in crop yield or specific weight between insecticide products, spray timing or their interaction (Tables 16 and 17).

Table 16. Mean yield (t/ha @ 85% dry matter) at Wendover in 2013 and 2014

Wendover 2013						
Product	Control	**Insecticide timing**				**Mean**
		1st adults	T1 + 7–10 days	1st eggs	1st Larvae	
	7.86					
Chlorpyrifos		8.09	8.00	7.96	7.46	7.88
Lamda-cyhalothrin		8.14	8.18	8.10	8.03	8.11
Thiacloprid		8.36	7.41	7.76	7.80	7.83
Mean		8.20	7.86	7.94	7.76	
SED for comparison of product means (36DF) = 0.27						
SED for comparison of timing means (36DF) = 0.31						
SED for comparisons within the body of the table (36DF) = 0.53						
Wendover 2014						
Product	Control	**Insecticide timing**				**Mean**
		1st adults	T1 + 7–10 days	1st eggs	1st Larvae	
	8.38					
Chlorpyrifos		8.56	8.58	9.09	8.64	8.72
Lamda-cyhalothrin		8.46	8.46	8.70	8.61	8.55
Thiacloprid		8.88	8.53	8.59	8.89	8.72
Mean		8.63	8.52	8.79	8.71	
SED for comparison of product means (36DF) = 0.13						
SED for comparison of timing means (36DF) = 0.15						
SED for comparisons within the body of the table (36DF) = 0.26						

Table 17. Mean specific weight (kg/hl @ 85% dry matter) at Wendover in 2013 and 2014

Wendover 2013						
Product	Control	**Insecticide timing**				**Mean**
		1st adults	T1 + 7–10 days	1st eggs	1st Larvae	
	72.03					
Chlorpyrifos		69.46	71.82	71.51	70.20	70.75
Lamda-cyhalothrin		70.90	71.32	71.25	69.53	70.75
Thiacloprid		70.06	68.52	70.44	70.88	69.98
Mean		70.14	70.55	71.07	70.20	
SED for comparison of product means (36DF) = 0.848						
SED for comparison of timing means (36DF) = 0.980						
SED for comparisons within the body of the table (36DF) = 1.700						
Wendover 2014						
Product	Control	**Insecticide timing**				**Mean**
		1st adults	T1 + 7-10 days	1st eggs	1st Larvae	
	71.53					
Chlorpyrifos		72.38	71.14	71.95	71.41	71.72
Lamda-cyhalothrin		70.83	70.75	70.92	73.37	71.47
Thiacloprid		73.01	71.40	71.51	70.92	71.71
Mean		72.07	71.10	71.46	71.90	
SED for comparison of product means (36DF) = 0.596						
SED for comparison of timing means (36DF) = 0.688						
SED for comparisons within the body of the table (36DF) = 1.192						

4.3.2. Royston and Wendover 2015

In 2015 at Royston 14.5% of tillers were infested with saddle gall midge but only 9.6% at Wendover (Table 18). Insecticide treatment significantly decreased the level of tiller infestation by 64% at Royston ($P<0.01$). There was also a significant difference in percentage tillers infested by saddle gall midge between products ($P<0.01$). Lowest levels of infestation were recorded where lamda-cyhalothrin was applied. Both Lambda-cyhalothrin and thiacloprid had a significantly lower level of tiller infestation than where chlorpyrifos was used ($P<0.05$). There was also a trend for plots treated with lamda-cyhalothrin to have the lowest level of tiller infestation at Wendover. There was no significant interaction between product and insecticide timing at either Royston or Wendover.

Percentage tiller infestation differed significantly between insecticide timings at Royston (P<0.05). Sprays applied at the first sign of adults were most effective and both this treatment and sprays applied 14 days after first adults had significantly lower tiller infestation than sprays seven days after first adults (P<0.05). There was no significant effect of spray timing on tiller infestation at Wendover and no significant interaction at either Wendover or Royston.

Table 18. Mean % tillers infested with saddle gall midge larvae at Royston and Wendover, 2015

Royston 2015					
Product	Control	**Insecticide timing**			**Mean**
		1st adults	1st adults + 7 days	1st adults + 14 days	
	14.5				
Chlorpyrifos		3.8	16.6	9.8	10.0
Lamda-cyhalothrin		1.9	1.7	0	1.2
Thiacloprid		0.7	10.8	1.2	4.3
Mean		2.1	9.7	3.7	
SED for comparison of product means (27DF) = 2.52					
SED for comparison of timing means (27DF) = 2.52					
SED for comparisons within the body of the table (27DF) = 4.36					
Wendover 2015					
Product	Control	**Insecticide timing**			**Mean**
		1st adults	1st adults + 7 days	1st adults + 14 days	
	9.6				
Chlorpyrifos		8.7	6.5	6.0	7.1
Lamda-cyhalothrin		0	2.1	2.1	1.4
Thiacloprid		8.4	4.0	6.0	6.2
Mean		5.7	4.2	4.7	
SED for comparison of product means (27DF) = 2.71					
SED for comparison of timing means (27DF) = 2.71					
SED for comparisons within the body of the table (27DF) = 4.69					

The percentage plants infested with saddle gall midge differed significantly between insecticide treated and untreated plants at Royston (P<0.001, Table 19) and Wendover (P<0.05). Insecticide treatment at Royston reduced plant infestation by 62%. There was also a significant difference in plant infestation between products (P<0.01). The lowest level of plant infestation was in plots treated with lamda-cyhalothrin but both this product and thiacloprid were significantly better than chlorpyrifos (P<0.05). At Wendover lamda-cyhalothrin significantly decreased plant infestation in comparison with chlorpyrifos (P<0.05). At Royston sprays applied to control first adults and those applied 14 days later had a significantly lower level of plant infestation than sprays applied seven days after first adults were seen (P<0.05). There was no significant effect of spray timing at Wendover and no significant interaction between timing and product at Wendover or Royston.

Table 19. Mean % plants infested with saddle gall midge larvae at Royston and Wendover, 2015

Royston 2015					
Product	Control	**Insecticide timing**			**Mean**
		1st adults	1st adults + 7 days	1st adults + 14 days	
	35.0				
Chlorpyrifos		10.0	32.5	25.0	22.5
Lamda-cyhalothrin		7.5	7.5	0	5.0
Thiacloprid		5.0	27.5	5.0	12.5
Mean		7.5	22.5	10.0	
SED for comparison of product means (27DF) = 4.40					
SED for comparison of timing means (27DF) = 4.40					
SED for comparisons within the body of the table (27DF) = 7.62					
Wendover 2015					
Product	Control	**Insecticide timing**			**Mean**
		1st adults	1st adults + 7 days	1st adults + 14 days	
	20.0				
Chlorpyrifos		22.5	15.0	12.5	16.7
Lamda-cyhalothrin		0	5.0	5.0	3.3
Thiacloprid		17.5	12.5	10.0	13.3
Mean		13.3	10.8	9.2	
SED for comparison of product means (27DF) = 4.99					
SED for comparison of timing means (27DF) = 4.99					
SED for comparisons within the body of the table (27DF) = 8.64					

Insecticide treatment decreased the number of galls per tiller at Royston by 78% (P<0.05, Table 20). There was also a significant difference in galls per tiller (P<0.05) between products at Royston. Lamda-cyhalothrin and thiacloprid were significantly better at reducing gall number than chlorpyrifos (P<0.05). Lowest numbers of galls were recorded where lamda-cyhalothrin was used. Gall numbers per plant tended to be lowest where sprays were targeted at first adults at Royston but differences from other spray timings were not statistically significant. There was no significant interaction between insecticide product or spray timing at either Royston or Wendover.

There was no significant effect of insecticide product or spray timing on crop yield at Royston or Wendover and no significant interaction between these variables (Table 21).

Table 20. Mean numbers of saddle gall midge galls/tiller at Royston and Wendover in 2015

Royston 2015					
Product	Control	**Insecticide timing**			**Mean**
		1st adults	1st adults + 7 days	1st adults + 14 days	
	0.67				
Chlorpyrifos		0.10	0.64	0.25	0.33
Lamda-cyhalothrin		0.04	0.03	0	0.03
Thiacloprid		0.01	0.24	0.02	0.09
Mean		0.05	0.31	0.09	
SED for comparison of product means (27DF) = 0.110					
SED for comparison of timing means (27DF) = 0.110					
SED for comparisons within the body of the table (27DF) = 0.190					
Wendover 2015					
Product	Control	**Insecticide timing**			**Mean**
		1st adults	1st adults + 7 days	1st adults + 14 days	
	0.23				
Chlorpyrifos		0.19	0.21	0.23	0.02
Lamda-cyhalothrin		0	0.04	0.02	0.21
Thiacloprid		0.30	0.08	0.07	0.15
Mean		0.16	0.11	0.11	
SED for comparison of product means (27DF) = 0.079					
SED for comparison of timing means (27DF) = 0.079					
SED for comparisons within the body of the table (27DF) = 0.137					

Table 21. Mean numbers of saddle gall midge galls/tiller at Royston and Wendover in 2015

Royston 2015					
Product	Control	**Insecticide timing**			**Mean**
		1st adults	1st adults + 7 days	1st adults + 14 days	
	10.16				
Chlorpyrifos		10.04	9.89	10.05	10.00
Lamda-cyhalothrin		10.13	9.73	9.78	9.88
Thiacloprid		9.98	9.82	9.94	9.91
Mean		10.05	9.82	9.93	
SED for comparison of product means (27DF) = 0.149					
SED for comparison of timing means (27DF) = 0.149					
SED for comparisons within the body of the table (27DF) = 0.257					
Wendover 2015					
Product	Control	**Insecticide timing**			**Mean**
		1st adults	1st adults + 7 days	1st adults + 14 days	
	9.85				
Chlorpyrifos		10.11	9.96	9.87	9.98
Lamda-cyhalothrin		9.97	9.91	10.00	9.96
Thiacloprid		9.69	9.61	10.22	9.84
Mean		9.92	9.83	10.03	
SED for comparison of product means (27DF) = 0.177					
SED for comparison of timing means (27DF) = 0.177					
SED for comparisons within the body of the table (27DF) = 0.306					

A summary of all lamda-cyhalothrin treatments including single sprays and programmes of sprays is given in Table 22. The percentage tillers infested differed significantly between treatments at both Royston and Wendover (P<0.01 and P<0.001, respectively). All insecticides decreased tiller infestation compared with the untreated control (P<0.05) but there were no statistically significant differences between individual spray treatments.

The percentage plants infested with saddle gall midge also differed significantly between treatments at Royston (P<0.001) and Wendover (P<0.01). As with the infested tiller data all insecticides significantly decreased plant infestation compared with the control (P<0.05) but there was no statistically significant difference between individual treatments.

Gall numbers per tiller differed significantly between insecticide treatments at Royston (P<0.01 and P<0.001, respectively). Again all insecticides significantly reduced gall number in comparison with the untreated control but individual spray treatments did not differ significantly.
There was no significant difference in yield between treatments.

Table 22. The effect of a range of single sprays and programmes of lamda-cyhalothrin on tiller and plant infestation with saddle gall midge, number of galls per tiller and yield (t/ha @ 85%DM)

Site	Lamda-cyhalothrin sprays and programmes of sprays							SED 18DF
	Control	1st adults (1)	1st adults + 7 days (2)	1st adults + 14 days (3)	1 + 2	2 + 3	1 + 2+ 3	
	% tillers infested							
Royston	14.5	1.9	1.7	0	3.1	0	0.8	3.11
Wendover	9.6	0	2.1	2.1	0	0	0.8	2.14
	% plants infested							
Royston	35	7.5	7.5	0	5	0	2.5	4.52
Wendover	20	0	5	5	0	0	2.5	4.37
	Galls/tiller							
Royston	0.67	0.04	0.03	0	0.09	0	0.01	0.168
Wendover	0.23	0	0.04	0.02	0	0	0.01	0.027
	Yield							
Royston	10.10	10.13	9.73	9.78	10.05	10.20	10.12	0.224
Wendover	9.85	9.97	9.91	10.00	10.20	9.68	9.80	0.329

4.4. Proposing thresholds for saddle gall midge

Dewar (2012) reported saddle gall midge is unlikely to have an impact on crop yield unless larval numbers are in excess of 500/m^2 or there are more than seven larvae/tiller. In the four field experiments conducted in this study, larval numbers in the soil never exceeded 369/m^2 and galls/tiller (the equivalent of larvae/tiller assuming each larva attacks a single tiller) were never greater than 0.7/tiller. These levels are well below the proposed thresholds so it is not surprising that, although insecticide treatment generally reduced pest infestation, there was no impact on yield. Under these circumstances there is no data to indicate that existing thresholds are incorrect and so they should continue to be used until such time that experimental data suggests that they require revision.

It seems likely that the risk of damage is a function of the number of larvae in the soil and the timing of adult emergence. Gratwick (1992) suggested that when egg hatch coincides with or is near to ear emergence yield is little affected. Conversely crops in the process of stem extension at the time of attack suffer much great effects on yield. This seems logical as the larvae have a longer period to feed on the stem and thus will have greater impact on the transportation of nutrients to the ear. Using the data generated from this study and that available in the literature it is possible to suggest a basic IPM strategy for saddle gall midge (Figure 22).

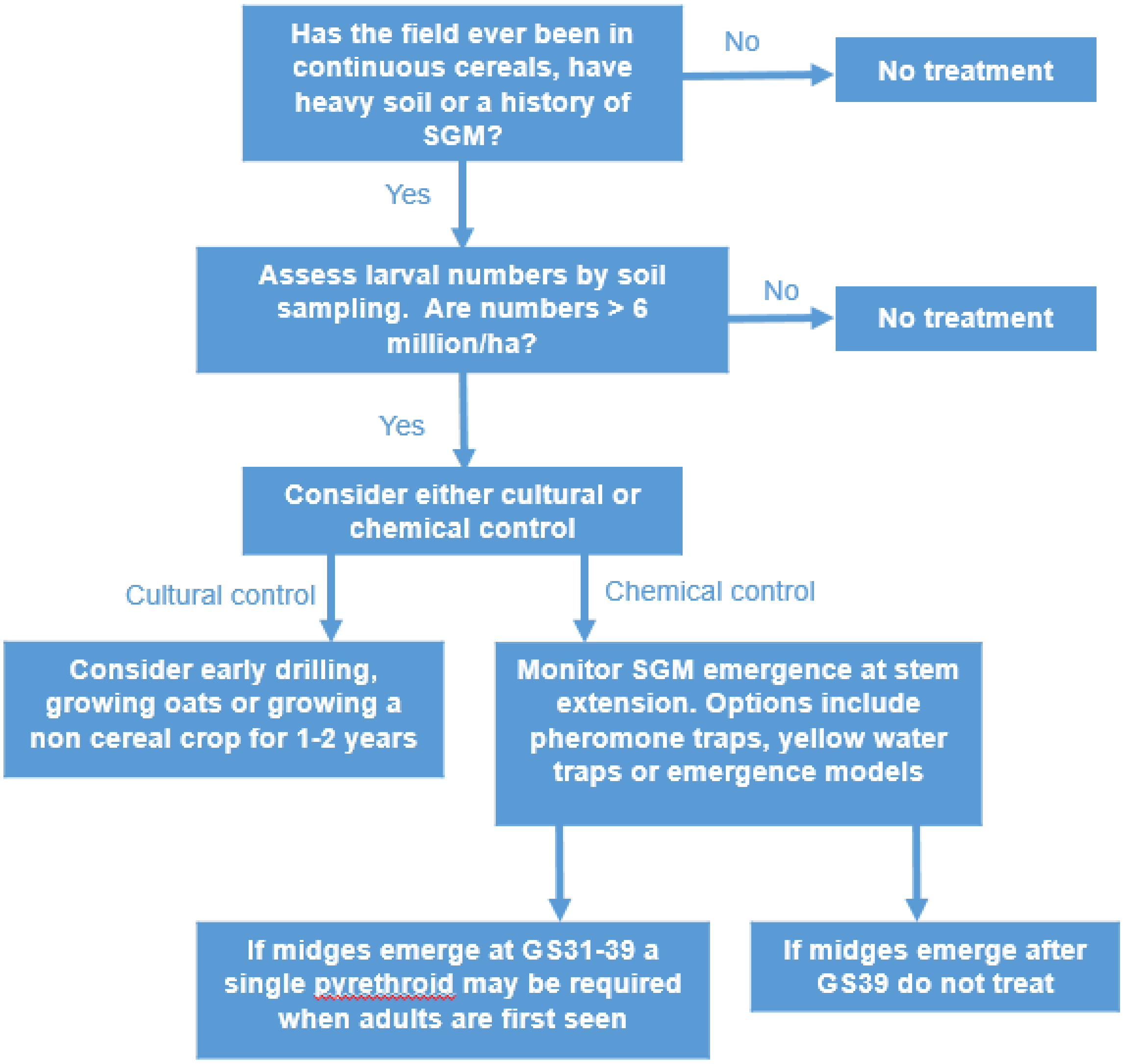

Figure 22. Basic IPM strategy for saddle gall midge (SGM)

Such a strategy would require annual monitoring of the levels of saddle gall infestation in soil at a number of indicator sites where the pest has caused problems in the past but this should be a relatively inexpensive exercise.

5. Discussion

5.1. Monitoring midge development

Soil sampling proved an effective way of assessing saddle gall midge numbers and monitoring their development in soil. By sampling in the top 20 cm of soil it was possible to recover about 78% of developmental stages of the pest. Larvae, pre-pupae and sclerotised pupae were all extracted from soil and photographed. No larvae were recovered within the earthen cells in which they overwinter possibly because they had already emerged from these before monitoring began. Alternatively it may be that the cells were destroyed by the soil washing procedures. Larvae were most commonly found with much lower numbers of pupae being recovered. It is difficult to say whether the pupal stages are inherently difficult to detect or whether there is significant mortality between the larval and pupal stages. The discovery of a fungal parasite of larvae at Sessay in North Yorkshire accounted for the low numbers of pupae found at this site as parasitised larvae did not proceed to the pupal stage. It would be interesting to determine the range of this parasite as it is possible that it is having a significant impact on larval mortality. The potential for its use as a biological control agent should also be investigated.

Despite the recovery of low numbers of pupae their detection did provide an early warning of adult midge emergence. Gratwick (1992) suggested that the adults emerge 10–20 days after pupation. Understanding when adult midges are likely to emerge helps in assessing the risk of crop damage from saddle gall midge. Crops attacked during stem extension are considered to be at significantly greater risk of losing yield than those that are attacked near to or during ear emergence. It seems unlikely that crops attacked at a late stage of growth would justify insecticide treatment unless there is a very large hatch of adult midges. In 2011, when anecdotal evidence suggested up to 70% of yield was lost, adult midges were recorded in large numbers on 22 April and were already laying eggs (Andrew Cotton, personal communication). Benchmark dates suggest that an average wheat crop might be expected to be at GS 31–39 between 10 April and 19 May so pest emergence and egg laying would have coincided with the susceptible stage of the crop. When this is combined with the very high numbers of pests that were seen in 2011, this would explain the dramatic effect on crop yield.

Soil sampling is laborious and time consuming and is something that is unlikely to be undertaken by individual farmers or agronomists. However, it would be possible to undertake annual monitoring at a number of indicator sites where the pest has been a problem in the past. This would provide an initial assessment of pest levels and also a warning of the likely timing of emergence in sites were visited at regular intervals. The combination of pest numbers and likely timing of adult emergence would give a good indication of the seasonal risk from saddle gall midge.

Developmental models based on soil and air temperature evaluated by Charlotte Rowley at Harper Adams University also show promise as a means of predicting the time of pest pupation and emergence. Using ADAS meteorological data collected from the monitoring sites in North Yorkshire and Buckinghamshire it was possible to predict midge pupation to within six days and adult emergence within eight days. Running these models is significantly less laborious and time consuming than soil sampling. If they can be further refined they could provide an early warning of midge emergence and data could be disseminated via the AHDB website.

If soil sampling or developmental models can be used to provide a warning of emergence of saddle gall midge this can then be confirmed by the use of yellow water traps or pheromone traps. Yellow water traps were more effective than either yellow sticky traps or emergence traps but have the disadvantage of being non-specific in what they catch. Anyone using water traps would therefore need to be able to pick out adult saddle gall midges from other insects caught. As with soil sampling this is unlikely to be something undertaken by individual farmers or agronomists although it would be possible to send the trap catch to a commercial laboratory to identify its contents. In this way traps would be used in a similar fashion to water traps that are used by Fera for monitoring of potato aphids. A network of traps could be run as a component of a saddle gall midge monitoring scheme.

The prototype pheromone traps developed by Charlotte Rowley at Harper Adams University were extremely effective at catching male saddle gall midge. The maximum catch in the pheromone traps was 300/trap/day in comparison with 7/trap/day in yellow water traps. These results suggest that the quantity of pheromone lure used in the traps could be significantly reduced and still provide a warning of midge emergence. Catches were so high that they could encourage unnecessary use of insecticides. It is possible that the traps attracted male midges from a wide locality rather than within the immediate area of the traps. Recovery of pupae of saddle gall midge by soil sampling suggested that field populations of the pest were much lower than the pheromone traps predicted.

In view of their potency for modifying the behaviour of male midges it is possible that synthetic sex pheromones have potential for controlling these insects by mass trapping (Hall *et al*., 2012) and this option could be considered for saddle gall midge. For example a trial was conducted with in New Zealand on the cecidomyiid midge *Dasineura mali* an important pest of apples (Suckling *et al*., 2007). A total 500 traps/ha were deployed and this supressed midge numbers by 94%–98% but the ultimate levels of pest damage were too low to assess the effectiveness of the treatment for control of the midge.

With further refinement pheromone traps for saddle gall midge could be a very useful means of monitoring emergence of the pest in much the same way as similar traps are used to monitor orange wheat blossom midge. It would also be interesting to investigate whether catches of male midges could be used as an indirect threshold of the need to control the females and the possibility that by deploying sufficient traps it might be possible to supress midge numbers below levels at which they cause significant damage.

5.2. Impact of saddle gall midge on crop yield

There was no clear relationship between uninfested and infested plants/tillers in terms of grain number per ear, weight per grain, yield of grain per ear or straw weight. Of seventy comparisons significant differences between uninfested and infested tillers were only recorded on 23 occasions. On these occasions there was an approximately even split between uninfested and infested tillers having the highest value for the various parameters measured. Saddle gall midge damage causes restrictions to the flow of nutrients to the ear which can result in poorly developed grains or even blind ears (Golightly & Woodville, 1974). These workers suggested a threshold of seven larvae per stem for wheat to justify insecticide treatment. In the four field experiments in this project pest infestation was significantly lower than the proposed threshold and never exceeded one larva per tiller. It is therefore not surprising that limited impact of saddle gall midge feeding was detected on infested tillers.

Correlations were also attempted between grain yield and numbers of galls per tiller. The resulting relationships were poor and never accounted for more than 27% of the variation in tiller yield. This is again probably due the low levels of pest infestation. Popov *et al*., (1998) showed a linear relationship between grains per ear and thousand grain weight and numbers of larvae per tiller. However, larval numbers per tiller ranged from 0–30 whereas in the current study there was never on average more than one gall per tiller. All data points would therefore to concentrated at the low end of pest infestation and not be expected to show significant variation in their impact on the growth parameters of the crop

5.3. Chemical control options for saddle gall midge

There were significant differences between insecticide products and also between spray timings for control of saddle gall midge. Significant effects of spray timings were recorded at Wendover in 2013 and 2014 and at Royston in 2015. In 2013 and 2014 sprays targeted at adult midges or eggs were generally better than those targeted at larvae. This is to be expected as once larvae start to feed they are physically protected from spray applications by the leaf sheath. In 2013 there was little difference between sprays applied at the first sign of adults, seven days later or at the first sign of eggs. In 2014 sprays targeted at first adults were significantly better than those targeted at eggs and in 2015 sprays applied at the first sign of adults or 14 days later were better than those applied seven days after first adults. Overall it would appear that a spray targeted at the first sign of adult midges is likely to be most effective but later sprays applied up to the appearance of midge eggs are also likely to give some control.

Insecticide products differed significantly in their efficacy against saddle gall midge in 2015 at both Royston and Wendover in data for % tillers infested, % plants infested and galls/tiller. Both lamda-cyhalothrin and thiacloprid were significantly better than chlorpyrifos at reducing levels of saddle gall midge infestation. Lamda-cyhalothrin had the lowest level of % plant and tiller infestation and lowest number of galls/tiller but was not statistically better than thiacloprid.

There was no significant interaction between insecticide product and spray timing for any of the variables assessed so the relative performance of insecticides was consistent across all spray timings.

Comparison of single sprays and programmes of sprays of lamda-cyhalothrin showed that all had significantly lower levels of % tiller and plant infestation and galls/tiller than the untreated control. Statistically there was no difference between any of the lamda-cyhalothrin treatments so a single spray was equally as effective as a programme of two or three sprays. It is possible that under higher levels of pest infestation programmes of sprays would have been most effective.

Previous work in Romania (Popov, 1998) supported the effectiveness of pyrethroid insecticides for saddle gall midge control. A single spray of alpha-cypermethrin as Fastac gave 63% control of the pest. At Royston in 2015 a single spray of lamda-cyhalothrin averaged over applications made at adult emergence or seven or 14 days later showed % tiller infestation was reduced by 92%, % plant infestation by 86% and the number of galls per tiller by 63%. The Romanian work also showed that best control of saddle gall midge was given by three sprays approximately two weeks apart but the level of pest infestation was much higher than in the current study with 90% of tillers attacked.

Although insecticide treatment decreased levels of saddle gall midge infestation there was no impact on crop yield. This result stresses the importance of assessing pest levels before deciding on whether it requires to be controlled. The concept that damage does not always equate to yield loss is one that will become increasingly important in pest risk assessment. With the number of available active ingredients for pest control declining it will become vital that these are used in a rational manner in order to minimise the potential risk of the development of resistance. Rational insecticide use is a vital component of IPM.

Currently there are no products with a label recommendation for control of saddle gall midge in the UK. This is probably due to the sporadic nature of the pest which makes it difficult to establish field experiments to provide data on the relative efficacy of insecticides for its control (Dewar, 2012). It is possible that a 120 day emergence approval could be considered in future if pest monitoring indicated a potential risk from saddle gall midge.

Following a non-dietary risk review the use of chlorpyrifos-ethyl or products containing chlorpyrifos-ethyl will no longer be possible after 1 April 2016. This product therefore will no longer be available for control of saddle gall midge. Fortunately both lamda-cyhalothrin and thiacloprid are potential alternatives and have been shown to be more effective than chlorpyrifos in the current study.

5.4. Proposing thresholds for saddle gall midge

The general levels of saddle gall midge infestation at the experimental sites were lower than had been experienced in the high risk years of 2010 and 2011. The maximum level of plant infestation was 33%, maximum level of tiller infestation was 18% and there was a maximum of 0.7 galls/tiller. Whilst control of these levels of infestation did not produce any impact on crop yield they do at least help to show when chemical control is unnecessary. Also during 2013 to 2015 adult emergence was never recorded as being before 9 May which is 17 days later than the high risk year of 2011. This is also likely to have an impact on the potential damage caused by the pest.

Dewar (2012) reports that few trials have established realistic thresholds for control of saddle gall midge. Work in Romania (Popov, 1998) suggested that 30 larvae/m^2 is sufficient to warrant control whereas at the other extreme Golightly and Woodville (1974) considered that numbers in excess of 500/m^2 are required before there is any economic damage. In the present study numbers of larvae exceeded 30/m^2 at all experimental sites and there was no yield response to control of this level of pest infestation. This therefore raises doubts over the validity of the Popov threshold. In view of the sporadic nature of the pest it is difficult to locate sites at which the level of pest infestation is sufficiently high to validate the threshold of Golightly and Woodville (1974). However, in the absence of any contradictory evidence it is suggested that this should be used for the time being. Golightly and Woodville (1974) also proposed a threshold of seven larvae per plant although once larvae are present the current study shows that they are very difficult to control. This threshold is only likely to be of use retrospectively when trying to account for any impact of saddle gall midge on yield. The larval threshold is similar to a Danish threshold of five eggs/tiller (Woodville, 1973). Assessing egg numbers can be difficult and time consuming and it is also unclear what proportion of eggs hatch to become saddle gall midge larvae. However, in the absence of an alternative this threshold does provide an indication of the level of pest infestation required to trigger insecticide sprays later in the development of the crop and where the emergence of adults has not been monitored. In the current study numbers of larvae never exceeded one per tiller so it is likely that egg numbers were well below the five per tiller threshold.

Yield loss due to saddle gall midge is probably a function of the timing of midge emergence and pest numbers. The 2010/11 outbreaks seem to have resulted from an early emergence during stem extension and large numbers of the pest. History suggests that this is an infrequent occurrence and so regular monitoring of saddle gall midge populations is vital to help predict those seasons in which the pest is likely to be damaging.

5.5. Conclusions and take home messages

The main conclusions and take home messages from this project are summarised below for each of the objectives.

5.5.1. Monitoring midge development

- Soil sampling was an effective method of assessing levels of saddle gall midge and monitoring its development.
- All developmental stages of the pest (except the earthen cells in which it overwinters) have been identified and photographed.
- Larger numbers of saddle gall midge larvae were recovered than of pupae.
- A fungal parasite *Lecanicillium* spp was identified at Sessay in North Yorkshire and had a dramatic effect on larval development such that few became pupae.
- Detection of midge pupation provides an early warning of adult emergence and is an important component of risk assessment for the pest. Adults usually emerge 10–20 days after pupation.
- Models developed at Harper Adams University which use soil or air temperature show promise in predicting saddle gall midge pupation and emergence. The accuracy of prediction of pupation was up to six days and up to eight days for adult emergence.
- Yellow water traps were more effective than yellow sticky traps or emergence traps at catching saddle gall midge adults.
- Prototype pheromone traps developed at Harper Adams University were very effective at trapping adult male saddle gall midge. Catches of midges were approximately 40 times higher than yellow water traps.

5.5.2. Impact of saddle gall midge on crop yield

- There was no clear relationship between larval infestation and crop yield. Pest infestation was less than one larva per tiller in all field experiments and probably too low to affect grain number or grain yield.

- There was a poor correlation between grain yield and the number of saddle gall midge galls/tillers probably due to the low level of pest infestation.

5.5.3. Chemical control options for saddle gall midge

- Chemical control of saddle gall midge reduced tiller infestation by up to 92%, percentage of plants infested by up to 86% and numbers of galls/tiller by up to 63%.
- Despite effective pest control there was no impact on crop yield indicating that damage does not always equate to loss of yield.
- Sprays targeted at the first appearance of saddle gall midge adults were generally most effective at reducing pest infestation.
- Treatments applied up to the appearance of eggs also gave some control of the pest.
- Sprays targeted at saddle gall midge larvae were ineffective.
- Both lamda-cyhalothrin and thiacloprid were more effective than chlorpyrifos at controlling saddle gall midge although the differences were not always statistically significant.
- Sprays of lamda-cyhalothrin generally resulted in the lowest levels of pest infestation but this product was not always statistically better than thiacloprid.
- A single spay of lamda-cyhalothrin was as effective as a programme of up to three sprays although more than one spray may be required at a higher level of pest infestation.

5.5.4. Proposing thresholds for saddle gall midge

- Levels of saddle gall midge were generally too low to make any progress on the development of threshold.
- Results showed that despite up to 33% plant infestation, 18% tiller infestation and 0.7 galls/tiller there was no impact on yield.
- Emergence of saddle gall midge adults during stem extension is likely to have a greater impact on yield than emergence at or near ear emergence.
- The current threshold of greater than 500 larvae/m^2 should continue to be used until experimental evidence suggests otherwise.
- An egg threshold of five eggs/tiller may be useful where adult emergence is not monitored.
- A basic IPM strategy is proposed to help assess the risk of saddle gall midge damage and encourage rational insecticide use against the pest.

5.6. Potential further research

There are a number of areas of future potential research and these are outlined below:

Further investigation of the parasitic fungus *Lecanicillium* spp.

- How widespread is the fungus? Is it commonly associated with saddle gall midge and is it having an impact on the pest?
- What is its potential for use as a biological control agent?
- What factors encourage fungal development?

Further development of pest monitoring.

- Refine pest development models from Harper Adams University to possibly take into account soil moisture.
- Refine pheromone traps so that they catch less midges and consider whether male catches could be used as a threshold for control of female midges.
- Consider potential for mass trapping with pheromone traps to suppress midge numbers.

Development of a saddle gall midge monitoring programme

- The main problem with this pest is its sporadic nature. Therefore regular monitoring is required to predict risk on an annual basis. The scheme could be administered by AHDB and results disseminated via the web site.

- Consider using soil sampling at representative sites with a history of the pest.
- Use models to predict pest emergence and traps to confirm their presence in the crop.

Develop pest threshold

The sporadic nature of the pest makes it difficult to develop threshold work.

- Consider using annual monitoring to locate sites with high pest populations and undertake opportunistic field experiments to gather further data on the impact of the pest on yield.

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