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Project identification

1. Defra Project code: CH0220
2. Project title: Cabbage Stem Flea Beetle: evaluating management of Winter oilseed rape on farm for maximum margins
3. Contractor organisation(s): NIAB
   93 Lawrence Weaver Road
   Cambridge
   CB3 0LE
4. Total Defra project costs (agreed fixed price): £136,980
5. Project: start date 01/08/20
   end date 31/12/23

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N/A

Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Oilseed rape (OSR) is a very important part of many arable rotations, it provides opportunities to control problem weeds, as a flowering crop it has the potential to increase biodiversity and provides an excellent break crop ahead of cereal crops. Cabbage stem flea beetle (csfb; *Psylliodes chrysocephala* L.) is a major threat. Csfb is also moving into areas of the UK that were previously unaffected. Since the ban on neo-nicotinoid insecticides, there has been a decline in OSR production which has had an impact throughout the supply chain. Pyrethroid resistance is also widespread in csfb populations making conventional insecticidal controls ineffective in many areas. A range of integrated pest management (IPM) strategies will be needed to help farmers establish and manage winter OSR effectively within the context of higher csfb pressure. This project took a farmer-centred adaptive learning approach to support innovation on-farm and uptake into practice so that findings could be shared and tested quickly in the face of the challenge to winter OSR from csfb.

The project objectives were to:

- Develop and evaluate monitoring tools that will enable farmers to make effective decisions on if/when/how to intervene to limit the impact of csfb.
- Establish UK OSR farmer network so that the on-farm evaluation of practices and the implementation of on-farm monitoring can be grounded within a wider understanding of the breadth of UK practice.
- Carry out on-farm evaluations of alternative management interventions.
- Carry out targeted trials (large or small plot as appropriate) to demonstrate novel/innovative approaches.
- Support effective interaction and learning between all combinations of researchers-farmers and industry partners using on-line conferences/webinars, open days and workshops triggering further innovation and stimulating alignment of industry-funded initiatives as appropriate.

Two further objectives were added as part of a project extension:

- Develop and evaluate robust methods for monitoring the emergence of csfb adults to inform potential IPM strategies.

- Investigate methods for extraction of csfb pupae from soil samples to help develop better understanding of the csfb lifecycle in order to inform potential IPM strategies.

The csfbSMART network (an acronym for “Sharing Management and Research Tools”) was established in 2020 via a range of media e.g. email, the farming press; a targeted presence on social media was valuable to establish the network and provide regular communications. The csfbSMART network gave growers and agronomists a route to share and to channel observations to the project team; these interactions were essential to shape the project’s direction after each research step. The csfbSMART network was used to gather geo-coded observations of the csfb pest in real time using targeted questions with simple answer choices. This provided a simple way of obtaining meaningful information without it being onerous to the growers at a busy time. Regular in-season updates were sent out rapidly via the csfbSMART network to help in decision making.

Between 2015 and 2019 NIAB deployed a crowd-sourced farmer assessment of OSR establishment and csfb adult feeding damage. In 2020, within this project, this survey was repeated. Data analysis, across all survey years, showed that year and drilling date were key factors in predicting csfb adult feeding damage. Recorded intensity of crop damage increased from 2015 to 2019; in general, crops drilled in September showed the highest levels of damage. Initially, the most severe crop damage occurred in the south/central regions of England (e.g. Herts, Cambs, Beds). In recent years, csfb adult damage has spread north and west. The risk of csfb damage appears linked to weather and seedbed conditions at drilling, together with the timing of drilling in relation to the number of csfb adults present.

The use of yellow water traps, as a simple method of assessing the number of adult csfb present at any given time, was rolled out to the csfbSMART network in summer 2021. Adult numbers trapped peaked in September. In 2022, growers were asked to indicate how many csfb adults they were seeing at harvest (none, hardly any, quite a few, millions). When the csfbSMART network reviewed these data, it appeared that they indicated that some csfb adults had not left the soil before harvest. This then led to the development of targeted methods to determine when the csfb adults emerge from the soil.

In 2023 controlled entomological studies were carried out. Standardised numbers of larvae and pupae were counted and the changes in populations were tracked using soil extraction with flotation methods. However, there were very low retrieval rates resulting in it not being possible to deduce additional information about the csfb lifecycle in this study. To explore whether csfb now also diapause as larvae or pupae in the soil over summer, and if so, at what depth below the surface, soil samples were collected from two fields where emergence trapping was taking place in spring/summer 2023. There were differences in csfb numbers between sites; csfb were found in the soil in good numbers to late June, and some as late as mid-July. The majority of insects were found in the top 30 mm of soil. These studies highlight that conventional understanding of the csfb lifecycle needs to be re-evaluated to underpin development of IPM strategies for csfb.

csfbSMART network discussions (during 2020) highlighted that the csfb stem larvae burden was important in determining crop success/failure. In autumn 2021, csfb stem larvae numbers, together with crop management information, were measured for over 600 geo-located commercial crops. A simple stem evacuation method was used; this method was chosen as it can be rolled out simply on-farm. The csfb larval numbers ranged from 0 to 645 csfb larvae/10 stems extracted, with a mean of 83. There was some indication of a regional pattern with significantly lower stem larvae numbers in the north of England and Scotland. Drilling dates in the second half of August were associated with higher csfb stem larvae numbers than early and later drilling dates. No differences between OSR varieties were observed. The use of insecticides had no impact on stem larvae numbers confirming that conventional csfb controls are now ineffective in many areas.

Plot trials were established in summer 2021 to see whether blends of OSR varieties could be used as part of an IPM control strategy. On both sites, Aspire had slightly lower numbers of stem larvae, followed by Aurelia and then DK Expectation. However, there was no indication when individual varieties were sampled within the variety blends that csfb adults had preferentially laid eggs on any particular variety.

A case study site (in the 2021 stem larvae survey) had shown marked improvement in OSR establishment and low stem larvae numbers where there were long-lasting companion crops. In 2022, a series of simple on-farm trials were planned to provide indicative data on the impact of long-lasting companion crops on stem larvae numbers and OSR crop performance. However, due to the summer drought in 2022, only five on-farm sites were established. The number of stem larvae present were reduced in the presence of the diverse companion crops across all the trials. This benefit does not accrue from all companion crops; for example, no reduction of csfb stem larvae numbers were seen where spring beans were grown as a companion. Further research is needed to allow effective selection and deployment of companion crops within an IPM strategy.

The csfbSMART network highlighted a potential relationship between the damage to new OSR crops and proximity to a previous crop. In 2023, we were able to use satellite imagery to confirm that crop failure due to feeding damage by csfb adults was more likely where the new OSR crop was surrounded by fields where OSR had recently been harvested. In autumn 2021, a limited number of insect emergence traps were deployed to further help determine where and when csfb adults emerge from the soil. New steel mesh traps were developed and deployed in 2022 and 2023. The data collected after harvest in all years across 17 sites indicated that csfb adults were emerging from soil during August and into September, October and even November. In 2023, two sites, had emergence traps set up in the standing crop of OSR prior to harvest. The patterns of emergence were very different between the sites, but both sites showed late spring emergence and emergence of csfb adults in August and throughout September. This suggests that there may be csfb pupae still in the soil at and after OSR harvest. This may provide an opportunity for development of an IPM strategy targeting this vulnerable stage.

In 2022 we established a pilot study on farm to test the hypothesis that post-harvest cultivations of OSR stubble reduced the number of csfb adults emerging from the soil. Following the success of the pilot, a second series of experiments was carried out in 2023. Cultivations were carried out using locally available equipment with cultivation at different depths, shallow (straw rake), 50mm and 250mm. At all sites there was a marked reduction in the number of csfb adults measured after cultivating the OSR stubble soon after harvest. This confirmed that there is potential to reduce emerging csfb adult numbers by 50-90% using a targeted post-harvest cultivation of the previous season's OSR stubble. This will reduce the risk of damage caused both by csfb adult grazing damage at/soon after establishment and loss of crop vigour resulting from csfb stem larvae. There are differences in the success rate of different cultivators, and this is likely to relate to soil type and soil moisture. As cultivation was carried out soon after harvest, the growth of the OSR volunteers was not affected thus any potential trap crop benefit will be maintained.

Overall, the project highlighted that understanding of the csfb lifecycle is incomplete. The subterranean lifecycle of csfb is relatively poorly understood. A greater understanding of the csfb lifecycle will increase opportunities to develop new targeted monitoring tools (e.g. soil sampling) that can help growers make time critical decisions that reduce risk for the OSR crop and support the development of new IPM strategies. There is clearly potential to reduce the adult population using targeted post-harvest cultivations as part of an IPM strategy. A greater understanding of the csfb life cycle around the time of hatching and emergence is needed to develop this strategy further. In addition, evidence suggests that longer lasting companion crops for OSR show potential to reduce the number of csfb larvae whilst increasing biodiversity. These approaches currently fit with all the IPM elements within Sustainable Farming Incentive (SFI). It is important that, going forward, SFI stays up-to-date with developments regarding IPM across all crops, so that SFI options continue to support, and do not obstruct uptake in the future.

The csfbSMART network was successful in bringing together farmers, agronomists and others to share information. Rapid/real time data collection from farmers and advisors using digital tools that provide policy-relevant information is possible but is not cost free. Using simple online tools to help share information within the farming industry has proved to be a very valuable tool in this project but such networks require management to maintain engagement.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and

- any action resulting from the research (e.g. IP, Knowledge Exchange).

1 Background

Oilseed rape (OSR) is a very important part of many arable rotations, it has an ideal fit with the timing of operations, provides opportunities to control problem weeds, as a flowering crop it has the potential to increase biodiversity and provides an excellent break crop ahead of cereal crops. Cabbage stem flea beetle (csfb; *Psylliodes chrysocephala* L.) is a major threat to the UK oilseed rape industry. Since the ban on neo-nicotinoid insecticides, the UK area of winter OSR has progressively fallen. AHDB estimated the 2019 harvested area at 514 kha, Defra's estimate of the 2022 harvested area figure was 323 kha. In tonnage terms, production fell from 2.4 MT in 2015 to an estimated 1.2 million tonnes in 2023, despite an increase in OSR area from 2022 to 391,000 ha in 2023. The fall in production resulted from a 19% decrease in yield. The decline in OSR production has had an impact throughout the supply chain. In 2019, UK crushers looked to fill approximately 2 MT capacity and consequently they are having to import. For a sustainable future, some estimates suggest that OSR area needs to stabilise at around half a million hectares to prevent the risks of processing plants closing and jobs being lost (information from NFU Roundtable report, February 2020).

Csfb is no longer just a problem for the south-east of England. Csfb populations also appear to be moving into areas of the UK that were previously unaffected. Pyrethroid resistance is also widespread in csfb populations (Zimmer *et al.*, 2014; Dewar, 2017), making conventional controls ineffective in many areas (Nicholls, 2016. The pest problem appears to be highly dynamic, showing geographic spread and a high dependency on weather conditions for both adult activity and severity of larval infestation. A range of integrated pest management (IPM) strategies will be required to assist farmers establish and manage winter OSR effectively within the context of higher csfb pressure. Therefore, it is important to know as much as possible about the behaviour and ecology of both larval and adult stages in order to identify potential management interventions. This project was delivered in parallel with other projects more focussed on entomology and plant mechanisms, including work funded by AHDB (Project 21120185 led by ADAS, due to complete spring 2024) and BBSRC-funded (Grant BB/V015524/1 led by JIC with RRes, due to complete November 2025).

The source of information used by farmers is most often other farmers and it has been shown that the most effective approach to support innovation is by increasing farmers' control over the processes of research and emphasising the process of learning rather than the teaching of content (Deugd *et al.,* 1998). Hence a key aim was to engage farmers in processes of identifying and prioritising problems and opportunities with regard to csfb, testing and evaluating innovations for IPM and being partners in sharing the information gained. Therefore, this project took a farmer-centred adaptive learning approach to support innovation on-farm and uptake into practice so that findings could be shared and tested quickly in the face of the challenge to winter OSR from csfb.

As a result of this research design, the following report presents the research in sequence, with the details of methods used and the results obtained together with a discussion of the results for each step, showing the links and mapping the adaptive learning process.

2 Objectives

Objective 1 - Develop and evaluate monitoring tools that will enable farmers to make effective decisions on if/when/how to intervene to limit the impact of csfb. A range of research approaches will be evaluated in parallel. Robust methods for use on-farm to measure factors that are decision-critical for the WOSR crop under csfb challenge will be selected and then evaluated by farmers.

Objective 2 - Establish a UK OSR farmer network. We will draw out an active OSR farmer network (c. 200 farmers) from the participants in the "see, show and share" crowd-sourced farmer assessments who will document their OSR 'intervention bundles', provide critical overview to on-farm experiments (WP3) and provide benchmarks from across the UK so that the on-farm evaluation of practices and the implementation of on-farm monitoring can be grounded within a wider understanding of the breadth of UK practice.

Objective 3 - Carry out on-farm evaluations of alternative management interventions. We will work with existing farmer groups (2020) and expand engagement (2021, 2022) to implement robust on-farm evaluation of practices and on-farm monitoring approaches with split field comparisons of each practice (with at least 10 on-farm monitoring sites in total over the project life-time).

Objective 4 - Work with the NIAB OSR focus centre (NIAB-Duxford) to carry out targeted trials (2021/22 and 2022/23; large or small plot as appropriate) to optimise the break crop benefit for a following winter wheat crop and demonstrate novel/innovative approaches, e.g. biocontrol.

Objective 5 - Support effective interaction and learning between all combinations of researchers-farmers and industry partners to develop recommended bundles of monitoring/management approaches that are both effective and practicable through annual evaluation of outcomes within a cost-benefit framework using on-line conferences/webinars, open days and workshops; and to trigger further innovation and stimulate alignment of industry-funded initiatives.

From 31/3/22 **Objective 6** – Develop and evaluate robust methods for monitoring the emergence of csfb adults to inform potential IPM strategies.

From 31/3/23 **Objective 7** – Use methods for extraction of csfb pupae from soil samples to help develop better understanding of the csfb lifecycle to inform potential IPM strategies.

2.1 Achievement of objectives within the project

The delivery with the project is described briefly in relation to the objectives in the table below; the full methods, results and their implications are described in the following sections.

Objectives	Delivery within the project
Objective 1 - Develop monitoring tools for use on farm.	Successfully delivered. Tools that can directly help growers/advisors were developed, demonstrated and deployed including simple methods to measure stem larvae numbers
Objective 2 - Establish UK OSR farmer network	Successfully delivered. A network of 200 plus growers and advisors were brought together to share information. The network had a direct influence in steering the direction of the project.
Objective 3 - Carry out on-farm evaluations management interventions	Successfully delivered. The project has indicated that the use of companion crops can affect csfb stem larvae numbers. There is also strong evidence to suggest that the emergence of csfb adults can be affected by post-harvest cultivations.
Objective 4 - Carry out targeted trials (2021/22 and 2022/23)	Partially delivered. Trials were successfully carried out in 2021 including a national stem larvae project. Many companion crop trials in 2022 failed to be established due to drought. 2023 cultivation trials were delivered successfully.
Objective 5 – Support effective interaction and learning between all combinations of researchers-farmers and industry partners.	Successfully delivered. Interactions between all combinations of researchers-farmers and industry partners have taken place within the network and much more widely using a range of media including the national farming press and many workshops and presentations.
Objective 6 – Develop and evaluate methods for monitoring the emergence of csfb adults from the soil.	Successfully delivered. Emergence traps were designed and built and have worked successfully. Simple methods for collecting information from crowd sourcing have been successfully used.
Objective 7 – Develop and evaluate methods for extraction of csfb pupae from soil.	Partially delivered. Methodologies have been tested and evaluated but these methods require further development and understanding before they could form part of a farmer-led pest management strategy.

3 Research steps

3.1 csfbSMART network.

The project aimed to harness information from “on-farm” observations, with those observations coming primarily from farmers and agronomists. This required a geographically-spread network to be established. The csfbSMART network (an acronym for “Sharing Management and Research Tools”) was established in 2020 via a range of media e.g. the farming press (mainly the *Farmers Weekly*), snowball mailing through a range of industry contacts, including NIAB members. We also established a targeted presence on social media; with Twitter (now known as “X”) proving a very useful tool to share information (c. 650 followers) and build links with growers posting comments. Establishing the network took a substantial effort over many months but this was a fundamental requirement if the project was to succeed. The online network reached 220 people. The regular online update meetings had good attendances with up to 248 (December 7th, 2022).

The aim of the Network was threefold:

Firstly, the network gave growers and agronomists a route to channel observations and thoughts to the project team and share with one another; these interactions were key to shape the direction of the project at the end of each research step.

Secondly, questions could be sent out, requesting an answer which enabled us to gather geo-coded observations of the pest in real time. We used targeted questions with simple answer choices coded within an online form creator (Jotform) which could be used on any smart phone or gadget. This allowed answers to be sent in with only 3-4 keystrokes providing a simple way of obtaining meaningful information without it being onerous to the growers at a busy time.

Thirdly, it allowed information and regular in-season updates to be sent out rapidly during the research to help in decision making.

3.2 "See, show, share" crowd-sourced farmer assessment of OSR establishment and csfb adult feeding damage

NIAB had previously deployed a "see, show, share" crowd-sourced farmer assessment of OSR establishment to enable users to provide qualitative assessments of emergence and adult feeding damage between 2015 and 2019. The data have previously been used to show the impacts of the loss of neonicotinoids and develop damage maps confirming that csfb populations were moving into areas of the UK that were previously unaffected such as the north and west of England (Kightley, 2019).

This task aimed to enable users to quantify emergence and adult feeding damage (through photos) alongside qualitative assessments, and to identify whether it was possible to use these approaches to follow development of OSR crops e.g. observing larval infestation, vigour at stem extension and/or yield. We also aimed to mine the data from all the crowd-sourced surveys using multi-variate techniques to see if combinations of practices/site factors leading to successful establishment could be identified.

Methods:

For the 2016 and subsequent harvest years (excluding 2017) the survey used a crowdsourcing app, for which a link was provided to oilseed rape growers. On opening the link, it was possible to position a marker, or ‘pin’, onto a map to identify whole farms, or individual fields, for reporting. The survey asked respondents to describe crop damage on a scale of terms ranging from ‘no damage’ to ‘complete crop write off’, as well as other details of local agronomic practise, including variety type selection, seed treatments, number of insecticide applications, and time of sowing. Once the survey questions were completed, a symbol appeared on the map, indicating severity of damage. ‘Clicking’ on the individual pins allows readers to interrogate the data for that location. The data for each season was presented to NIAB members and stored for further analysis. The approach is relatively crude and subjective but provides a fast overview of the geographical distribution and intensity of csfb adult damage at establishment together with an analysis of some agronomic practices. In 2020, within this project, the survey was enhanced (through the addition of a photo step) alongside qualitative scoring using a citizen engagement platform (“Maptionnaire”). In this project, the data were consolidated within GenStat 22nd Edition Software. Statistical analysis was carried out using residual maximum likelihood (REML). REML can be regarded as an extension of multiple regression to the case where there are several error terms with different statistical characteristics.

Results and Discussion:

In each of the 5 years that the survey was operated, a good number of responses from growers were received providing information on the location and status of many oilseed rape crops and their condition after establishment. The data collection approach was developed to give an overview of the geographical distribution and intensity of the csfb problem quickly.

Although the data were qualitative, and the overall design was not intended for detailed statistical analysis. Data analysis shows that year and drilling date were key factors in predicting damage (Table 1). The intensity of crop damage recorded increased from 2015 to 2019; in general, crops drilled in September showed the highest levels of damage.

The mapped data show clearly that initially, the most severe crop damage occurred in the south/central regions of England (e.g. Herts, Cambs, Beds). In recent years, csfb adult damage has spread north and west. The key determinants of the seasonal impact were weather and seedbed conditions at drilling, together with the timing of drilling in relation to the number of csfb adults present.

Table 1. Mean damage to OSR crops after drilling due to the impact of csfb adult grazing. Damage was scored qualitatively, coded for statistical analysis and the numerical means were then linked back to the qualitative description.

Month of drilling	July	August	September	October
Sowing year				
2015		Mild damage	Mild/moderate damage	No damage
2016		Mild damage	Mild damage	
2018		Mild/moderate damage	Moderate/severe damage	
2019	Moderate/severe damage	Moderate damage	Severe damage	
2020	Mild/moderate damage	Mild/moderate damage	Mild/moderate damage	Moderate damage

3.3 Development of on-farm monitoring to support establishment decisions

Yellow water traps are used in many crops to trap a range of insects and so were consequently used by NIAB to catch csfb adults on a range of sites where oilseed rape had been planted in late summer 2019 with the aim of understanding the timing of appearance of the adults at the critical time of establishment of the new crop. A total of eleven sites were monitored twice weekly and the results showed a peak of activity on these sites through September (Figure 1).

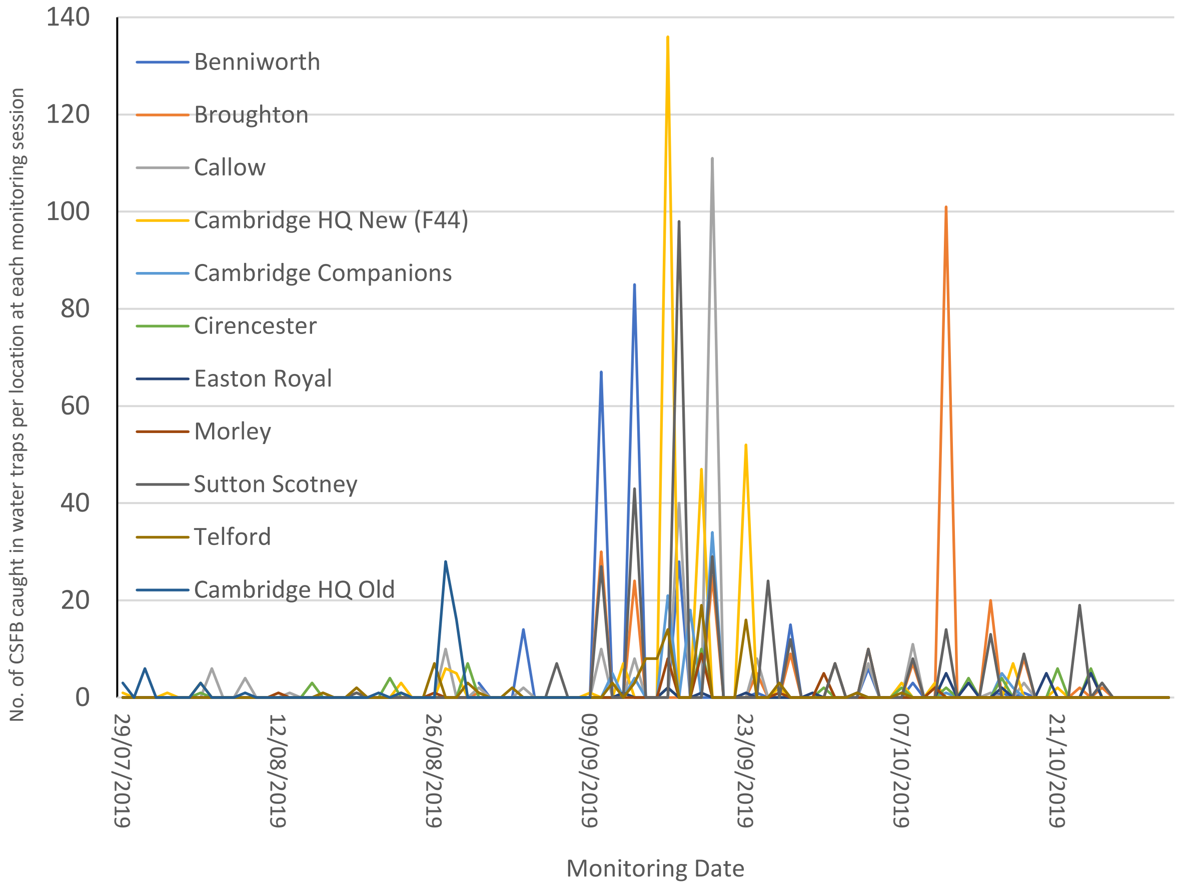


Figure 1. Number of csfb adults caught in water traps in late summer/early autumn 2019.

Farmers often see many csfb adults when they are harvesting the crop; these may be seen in grain trailers and grain stores. There is a perception that the amount of csfb adults seen at harvest is indicative of the issues that may be faced by the next crop, based on the assumption that all the csfb adults have left the soil before harvest.

Good seedbed conditions, soil/seed contact and available moisture are critical in the establishment of a small seeded crop such as OSR. The phrase often used is “drill into a moist seedbed”. This may not be very helpful to the grower as it can be interpreted in many different ways and the same preceding weather pattern will have a different outcome where soil types are different.

This task aimed to develop and roll-out simple methods to farmers to enable them to make data-informed decisions relating to establishment of new OSR crops.

Methods:

The use of yellow water traps, as a simple method of assessing the number of adult csfb present at any given time, was rolled out to the csfbSMART network in summer 2021. Several hundred traps were distributed to growers with instructions as to how they could use them to make decisions relating to the levels of csfb adults in the area at a time when they were making time-critical decisions relating to the new crop establishment. The recipients were asked to submit estimated numbers of csfb adults in the traps (0, <10, <50 and >50).

In 2022, we also rolled out a very simple ‘at harvest’ monitoring approach where growers were asked to indicate how many csfb adults they were seeing at harvest (none, hardly any, quite a few, millions). To help interpret these data, we also sought to understand what percentage of the csfb adults that were in the crop that was being harvested were actually placed into the grain trailers with the harvested crop.

Samples were taken from the discharge outlets of three different types of large commercial combine harvesters during operation in 2022 using extended poles and nets.

We developed advice relating to soil moisture using a simple video (https://youtu.be/WYQLn6nIcBA) that describes how a grower can take a baseline soil moisture assessment at any time during the growing season and then continue to record soil moisture in a simple and effective way using an empty food can (or similar). Over time, this will allow growers to understand their soil moisture levels which can then be compared with crop emergence data. This link was not tested further during the project as the work was not prioritised by the csfbSMART network.

Results and Discussion:

Over 300 submissions of csfb adult numbers from yellow water traps were delivered throughout the summer period after OSR harvest in 2021 (Figure 2). However, we quickly noted that growers were mainly focussed on submitting information only in the two weeks before and after their OSR drilling so that this approach of data collection does not give a robust picture across the whole late summer/ autumn period. Growers were also less likely to submit zero measures, even where they had observed them. As the data were submitted, it was possible to show the appearance of adults over time (Figure 2) and as the data was geocoded, we were able to answer requests about the pressure relating to specific geographical areas (Figure 3).

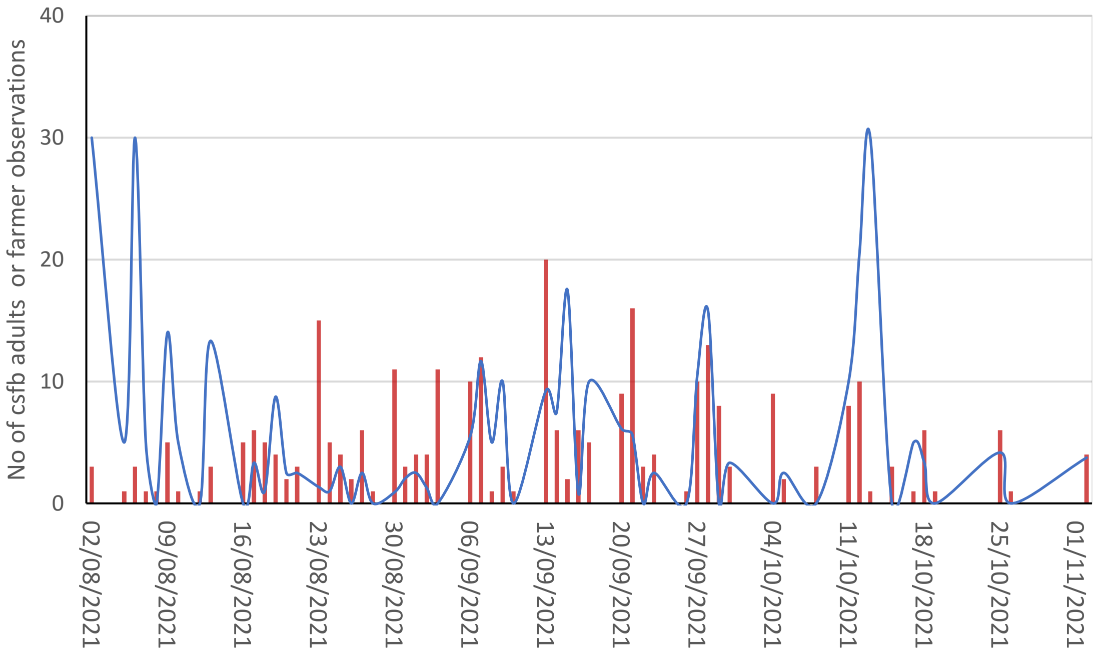


Figure 2. Number of csfb adults (average per date) observed in yellow water traps shown as line, with total number of observation returns on that date (as a column) from farmer submissions after harvest 2021.

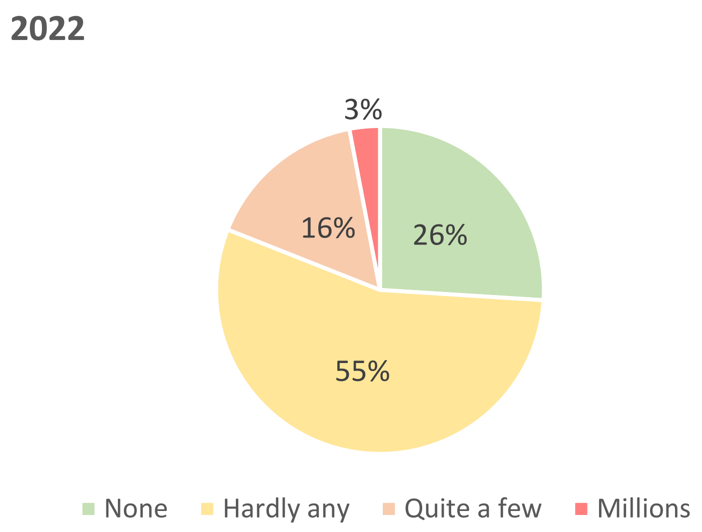
Figure 3. Map generated showing csfb pressure after harvest 2021 (a particular date or most severe observation at a site), generated from farmer submissions. The colour of the pin indicates severity (green = low; amber = moderate) and the number on the pin is the participant number.

None of the samples collected from the straw choppers and sieve discharges of combine harvesters had csfb adults present. This indicated that the majority of the csfb adults that entered the front of the combine harvester were passed through to the grain tank with the resultant seed. The majority of csfb adults observed by farmers with grain after harvest are therefore a significant proportion of the csfb adults present in the standing crop.

Initial feedback from the csfbSMART network had suggested that the numbers seen at harvest were extremely high, often referred to as “millions”. The csfbSMART network benchmarked the numbers by considering how csfb adults would appear: a large grain trailer (16 tonne capacity) has the floor area to accommodate about 18000 csfb adults (if spaced one to every 25mm^2). Figure 4 shows the data recording the perceptions of growers of the number of csfb adults at harvest in 2022 and 2023. There is a marked difference in the numbers observed between the years. In 2022, the harvest was following drought conditions and was ‘early’ in most areas. Overall, relatively few csfb adults were noted (median submission date 19/7/22). Harvest in 2023 was generally later, in many cases delayed by showers and more csfb adults were recorded (median submission date 28/7/23).

In general, few growers experienced very high numbers of csfb adults at harvest. When the csfbSMART network reviewed these data together with the data from the yellow water traps which showed peaks in September, it seemed to suggest that the perception that all csfb adults have left the soil before harvest might not be correct. This led us to develop and deploy targeted methods to determine when the csfb adults emerge from the soil (see Section 3.7).

a)



b)

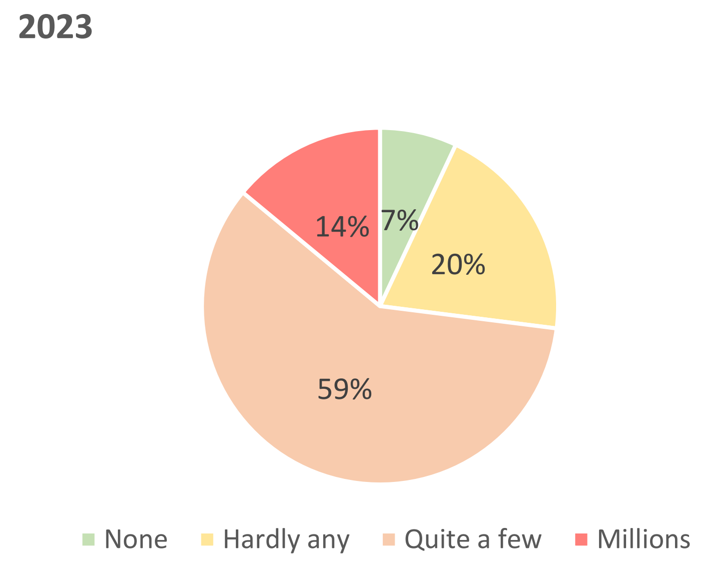


Figure 4. Farmer perception of csfb adult numbers: a) harvest 2022 (89 responses); b) harvest 2023 (56 responses).

3.4 Development of on-farm monitoring to support OSR management decisions - stem larvae counts 2021-22

If csfb larvae are present in OSR stems in sufficient numbers through the winter months, this can restrict growth, reduce yield and even cause complete crop failure. In 2019, an unknown but significant area of the national crop failed in late winter/early spring due to large stem larvae numbers having damaged the plants through the winter period. It became clear from discussions within the csfbSMART network in the first winter of the project (2020) that the stem larvae burden was as important as the challenges to establishment.

The size of the plant, the timing of the infestation/feeding and the weather are all variables affecting the survival rate of the plants. However, a simple on-farm method which allows growers to detect whether csfb larval levels are high or low could allow more effective management decisions. A simple stem evacuation method was originally described by Syngenta (https://youtu.be/M26Lx1dU4_E) that can be used very simply on farm to provide information to assist with decision making prior to inputs being applied to OSR crops in the spring. Currently, no precise threshold levels can be determined but measurements are needed to build knowledge of csfb stem larvae numbers and identify the ways in which those are affected the survivability of profitability of the crop.

This task aimed to conduct a large survey of csfb stem larvae numbers, together with crop management information, in geo-located commercial crops, working with farmers and advisors across the csfbSMART network.

Methods:

In the autumn of 2021, plans were developed to sample csfb stem larvae numbers of a wide range of OSR crops across the UK, capturing the cropping details and geographical locations. The csfbSMART network were key to this work and were engaged throughout the early winter of 2021. A sampling video was released in late 2021 (https://youtu.be/PNePRoo2q_Y). Samples were submitted together with information including the sampling location, variety, drilling date, use of companion crops, establishment methods and any other interventions used to help establish the crop. A freepost system was set up to make sure the sampled plants could be sent very simply to a range of NIAB centres in Hampshire, Cambridge and Gloucestershire by being dropped at a local post office. RStudio, running R version 4.1.1, was used for analysis by applying a simple general linear model with all terms, non-significant terms were removed until a minimum adequate model was obtained with the lowest achievable Akaike information criterion (AIC).

Results and Discussion:

During the winter of 2021-22, some 620 plant samples were received from farmers across the UK and processed to extract the stem larvae. Individual results were sent back to the growers and agronomists that had submitted them. This was the first such survey across such a wide range of commercial crops, as far as we are aware, and provided a large and complex data set.

51 OSR varieties were sampled from Aberdeenshire to Cornwall and all places in between. Drilling dates ranged from 28th July to 1st October 2021 with 55% of OSR crops drilled between the 10th and 24th of August. There were 6 variety mixes and 88 OSR crops were drilled with companion crops. For some crops additional management information e.g. use of insecticides, cultivations ahead of establishment were also noted.

The csfb larval numbers ranged from 0 to 645 extracted from 10 stems, with a mean of 83 and a median of 57 csfb larvae/10 stems. There was some indication of a regional pattern (Figure 5) with significantly lower stem larvae numbers in the north of England and Scotland. Significantly higher numbers of stem larvae were measured in samples from Cheshire, Shropshire, and north Wales.

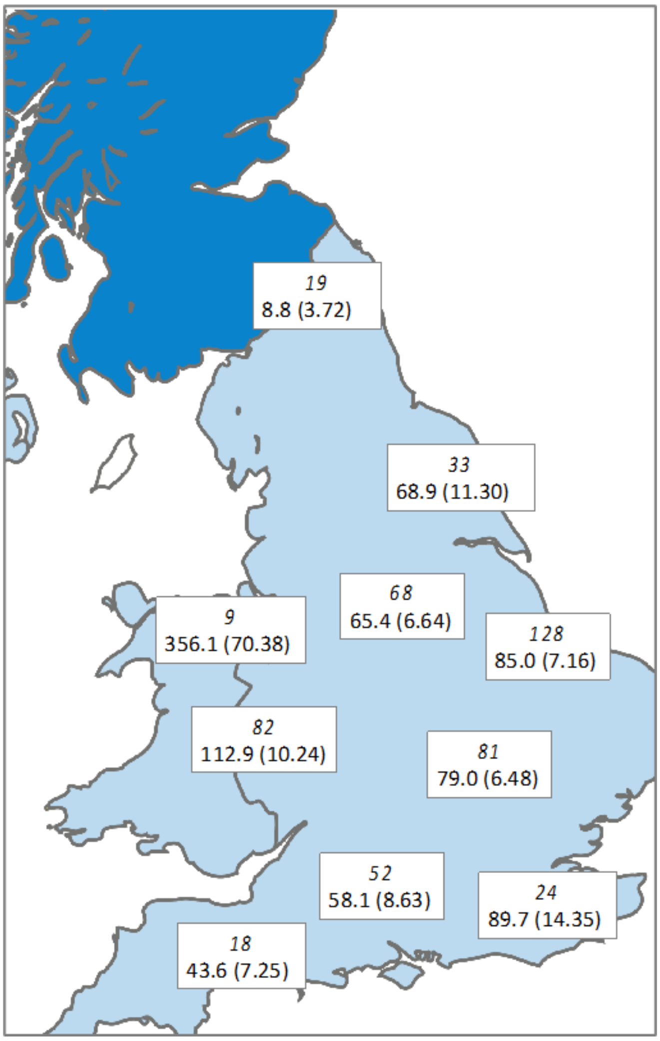


Figure 5. Regional distribution of samples submitted and csfb larvae count data. Data were grouped by county which were then further grouped. Each box is located on the map at approximately the centre of the region it represents. The box shows *Number of samples submitted* together with the mean (with SE) measured csfb larvae/10 stems.

The csfb larval count data were non-normal (strong positive skew) so the counts were $\log_{10}$-transformed for statistical analysis. Using this transformed count variable, a simple general linear model was used to explore the relationships in the data. Originally, drill date, companion plants, and application of any sort of fertiliser were included as variables, but companion plant identity and fertiliser use were excluded as variables from the final model as neither were significantly predictive of larval counts; this improved the model. As the study was observational, the location and management factors are not independent and hence the data can be used only to identify trends and develop hypotheses for future testing.

There is a curvilinear relationship between drilling date and csfb stem larvae numbers (Figure 6) with mid-range drilling dates associated with higher csfb stem larvae numbers than early and later drilling dates. Across the whole data set (excluding the significant outlier regions in the north of England and the north Wales/Cheshire cluster) 13% of the variation in csfb stem larvae numbers were explained by drilling date alone. Where there was sufficient data to look at this on a region-by-region basis, drilling date explained a high proportion of the variation (e.g. for Bedfordshire, 25% of the variation was explained by drilling date with a slightly earlier peak than for the whole dataset, Figure 5). These data fit with the observations of NIAB trials teams in recent years where trials drilled later in August than the surrounding crop have suffered from much higher levels of stem larvae, suggesting that the csfb adults have, where possible, laid eggs on younger plants when the choice is available.

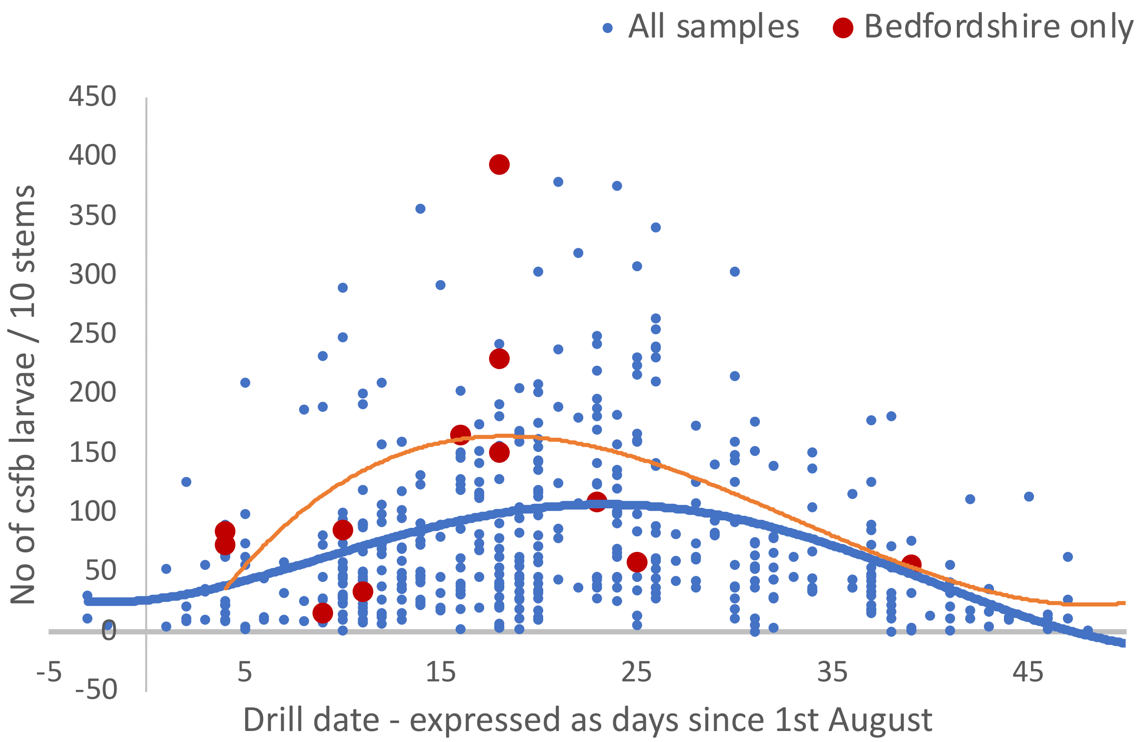


Figure 6. Relationship between drill date (days since 1st August 2021) and the larval counts per sample.

There was no significant difference between the csfb stem larvae count (for 10 stems) by variety (Table 2). However, given that conventional varieties are normally drilled at circa 80 seeds/m^2, whilst hybrid varieties are often drilled lower seed rates (commonly 45 seeds/m^2), this similar loading per stem may result in markedly different number of larvae/ha. This suggested difference was not able to be tested in the field. Other studies have shown some varietal differences in stem larval persistence suggesting that this relates to factors such as glucosinolate concentration in plant material (Bartlet *et al.*, 1996; Hopkins *et al*., 2008; Döring and Ulber, 2020). We found the highest populations on average associated with samples of Picto, Aardvark and V367OL Holl. However, these results were confounded with sampling locations and drilling dates. The relatively small number of Picto samples were clustered in Shropshire; V367OL Holl samples were collected around the UK but had a narrow higher risk drilling window (12th- 27th August). Aardvark samples were collected all over the UK, but 10 of the samples were clustered in Lincolnshire (with counts ranging from 142- 250 csfb larvae/10 stems). Similarly, while Crome and Matrix CL show the lowest median numbers, these results were also significantly confounded by the geographic locations. Crome samples were mainly collected from the north of England and Scotland where csfb risk is still relatively low; Matrix CL samples were mainly from fields in south Wales which were later drilled (after 7th September) adjacent to the previous OSR crop where volunteers were left as a cover crop overwinter. For both varieties, the maximum numbers collected in more typical cropping situations had stem larvae numbers (161 and 243 csfb larvae/10 stems for Crome and Matrix CL respectively) that are in line with values seen in the main block of varieties.

The most interesting variety data is from Extremus where the lowest maximum count was recorded (61 csfb larvae/10 stems). Although the data is from a small number of sites, samples were from around the UK, across the range of drilling dates (15th August to 15th September) and with/without companion crops. This variety is marketed for its vigorous autumn and early spring growth habit.

Table 2. csfb stem larvae counts for varieties with 5 or more samples submitted for assessment in winter 2021. Listed in decreasing order of median larval numbers, c = conventional varieties.

Variety	Type	No of crop samples	csfb stem larvae count No/10 stems		
			Min	Median	Max
Picto	Conventional	9	26	162	255
Aardvark	Conventional	20	18	140	304
V367OL Holl	Hybrid	9	27	100	226
DK Expedient	Hybrid	5	23	89	142
Amarone	Hybrid	8	9	78.5	211
Duke	Hybrid	20	1	75	496
Flamingo	Conventional	9	16	75	357
Aviron	Hybrid	14	9	74.5	562
Ambassador	Hybrid	37	4	74	376
Annika	Hybrid	12	9	68	241
DK Expansion	Hybrid	10	0	53.5	129
Codex	Conventional	13	14	53	109
Elgar	Conventional	10	29	51	98
Acacia	Conventional	61	2	50	394
Campus	Conventional	27	5	44	145
Aurelia	Hybrid	64	0	43	304
Rocca	Hybrid	7	4	38	126
Aspire	Conventional	43	2	37	203
Duplo	Hybrid	9	6	37	167
DK Extremus	Hybrid	5	11	30	61
Matrix CL	Hybrid	9	0	5	243
Crome	Hybrid	7	0	0	161

It is important to note that the use of insecticides had no impact on stem larvae numbers. 227 samples came from sites where insecticides were used, 82.96 csfb larva/10 stems were measured on average. In samples from sites with no insecticide use (287), 83.02 csfb larva/10 stems were measured on average. This confirms the earlier findings that conventional csfb controls are now ineffective in many areas (Nicholls, 2016).

Establishment of OSR with a companion crop is becoming more common; the data collected in this project do not show an overall reduction in stem larvae numbers from establishment with a companion crop overall (Table 3). When the data are broken down to show the companion crops/mixtures used, the data variability is too high to detect any differences.

Within the csfbSMART network, an interesting case study site in Cambridgeshire was identified where diverse and long-lasting companion crops were drilled together with OSR in 2021 (https://youtu.be/QmqLNJXghrs). An adjacent field that was sown with oilseed rape, but without the companion crops as a control, failed instantly due to adult csfb damage. Stem samples collected within the field showed very low larval counts (1 csfb larvae extracted from 40 stems) suggesting that the longer lasting companion crops had made a significant difference to egg-laying the previous winter. This OSR crop was almost zero input although one area did have a low level of herbicide to reduce competition, another area was mown and a third area was left without intervention to observe the effect of the companion crop management on OSR yield. Strips were harvested with a plot combine harvester (July 7th 2022); the yields were low by commercial terms (2-3 t/ha), however, they were very good for a very low input crop in this area. It is possible that these companion crops are masking the oilseed rape crop for much longer than the usual plants used to help crop establishment (buckwheat and berseem clover).

Table 3. csfb stem larvae counts for OSR crops with and without companion crops. Crops with companion crops also broken down to show the companion crop or mixture. Where there were 5 or more samples of a companion crop the means (SE) are also shown.

	No of crop samples	Mean	SE
OSR without companion crops	427	83.5	4.13
OSR with companion crops	88	79.6	8.44
Berseem clover	13	51.3	13.33
Buckwheat	28	91.3	13.13
Berseem clover, Buckwheat	15	106	31.05
Berseem clover, Fenugreek	3		
Berseem clover, red vetch	2		
Buckwheat, Fenugreek	3		
Buckwheat, Mustard	2		
Berseem clover, Buckwheat, Fenugreek	9	42.3	17.36
Berseem clover, Buckwheat, Mustard	2		
Berseem clover, Vetch, Fenugreek	1		
Berseem clover, Buckwheat, Vetch, Fenugreek	6	55	27.55
Clovers, Vetch	2		
Egyptian Clover, Spring Vetch, Phacelia, Buckwheat, Anthoxanthum	2		

Work in the AHDB-funded ADAS-led research projects have studied the benefits of different management techniques on crop establishment: tillage, fertiliser/organic amendment use. However, these practices in general, do not appear to have any major effect on csfb stem larvae numbers. The use or not of fertiliser of any kind (organic, synthetic, etc.) at establishment did not appear to make a significant difference to csfb stem larvae numbers.

3.5 Field trials of variety blends as part of a possible IPM strategy

Anecdotal information relating to preferential egg laying by csfb adults on different varieties led to a visual assessment of a wide range of small plot (2 metre or 3 metre width) OSR variety trials in 2020 and 2021. In these trials, there appeared to be higher levels of visual damage from csfb adults in some varieties irrespective of which randomised variety was in the adjacent plot.

This task aimed to see whether blends of OSR varieties could be used as part of an IPM control strategy and also to assess whether visual damage from csfb adults linked to csfb stem larval numbers.

Method:

Large scale plot trials were set up in Cambridgeshire and Dorset. 24 x 24 metre plots were planted using three varieties, Aspire, Aurelia and DK Expectation. A control plot of each variety was established and additionally plots of DK Expectation and Aurelia were drilled at 80% normal seed rate and Aspire was drilled at 20% normal seed rate at a 90^0 angle to allow for easy identification of the varieties. Stem larval counts were carried out during the winter on all plots.

Results and Discussion:

On both sites, there was a trend for Aspire to have the lowest number of stem larvae, followed by Aurelia and then DK Expectation (Figure 7). However, when the individual varieties were sampled, (Table 4) there was no effect shown within the variety blends to suggest that csfb had preferentially laid eggs on any particular variety. The only significant difference was that between the control plot of Aspire and the Aspire/DK Expectation plot, where the blend had significantly higher stem larvae numbers in both varieties. The trend for some varieties to have higher or lower stem larvae numbers when grown in larger plots under identical conditions suggests that if varieties appear that are more attractive to csfb adults for egg laying then the use of trap crops or blends to channel the larvae may prove useful as a component if an IPM strategy.

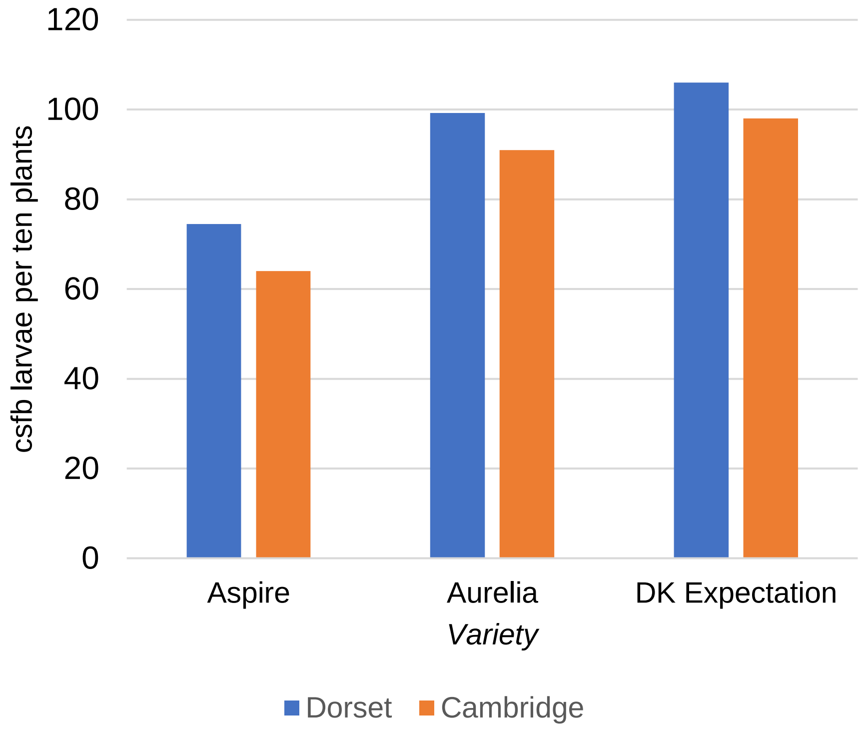


Figure 7. Stem larvae numbers per ten plants taken from each plot (December 2021).

Table 4. Stem larvae numbers per ten plants taken from each plot (December 2021).

Stem larvae numbers from variety blend trial	
Variety sampled	csfb larvae per 10 plants
Aspire	75
Aurelia	99
Expectation	106
Aspire from blend with Aurelia	109
Aurelia from blend with Aspire	78
Aspire from blend with DK Expectation	126
DK Expectation from blend with Aspire	116

3.6 Role of long-lasting companion crops - stem larvae counts

Building from the indicative findings of the impact of long-lasting companion crops on csfb stem larvae counts in OSR, a series of on-farm trials using longer-lasting companion crops with OSR were planned for 2022-23.

This task aimed to provide some indicative data on the impact of long-lasting companion crops on stem larvae numbers and OSR crop performance.

Method:
We planned to use simple demonstrations where the number of trials provided the replication, rather than use more complex replicated plot designs on-farm. Companion crop seed mixes were identified and sourced through a supplier with a detailed knowledge of the types of companion crops of interest. However, due to the summer drought in 2022, coupled to the potential establishment issues in areas with high levels of csfb, many of the csfbSMART network growers elected not to drill OSR in summer/autumn 2022 and it was possible to establish only five on-farm sites.

In Cambridgeshire, four large plots of companion crop mixtures were established in a winter oilseed rape crop, details of the mixtures are given in Table 4. Four sites were established in Shropshire with plots with and without the diverse companion crop in large plots.

The companion crop mixture included:

Buckwheat	4.0 kg/ha
NACRE vetch	5.5 kg/ha
Phacelia	1.0 kg/ha
Linseed	2.0 kg/ha

Site 1 was a several hectare block in the centre of a large field of oilseed rape, Sites 2 and 3 were strips of the OSR + diverse companion crops (24 m wide) within commercial oilseed rape crops and Site 4 had the OSR + diverse companion crop included in the headlands of a commercial crop.
Stem larval counts were carried out in December 2022.

Results and Discussion:

The plots established well (Figures 8 & 9).

a) 

b) 

Figure 8. a) Established oilseed rape with a companion crop of beans; b) Established oilseed rape with mixed companion crops including linseed and phacelia, Cambridgeshire December 2022.

Figure 9. Companion crop trial (Shropshire Site 2) December 2022 with phacelia visible above the crop.

The number of stem larvae present were reduced in the presence of the diverse companion crops across all the trials (Table 5 and Table 6). These data support the findings of the case study site within the stem larvae survey (Section 3.4). The Cambridgeshire companion crop trial highlights that this benefit does not accrue from all companion crops; no reduction of csfb stem larvae numbers were seen where spring beans were grown as a companion. These findings suggest that further research work would be of value to better understand the mechanisms governing how the companion crops are reducing stem larvae counts to allow effective selection and deployment of companion crops within an IPM strategy. Use of multispecies crops in this way can also bring wider benefits e.g. to biodiversity. As part of the current Sustainable Farm Incentive (SFI), a multispecies winter cover from Nov-Jan is supported by a payment (SAM2). These is also an SFI option if no insecticides are used (IPM4). Such payments may also incentivise the adoption of multispecies companion crops with OSR.

Table 5. Stem larvae numbers in companion crop trial, Cambridgeshire December 2022.

	Companion Crop	Seed rate	Stem larvae count, December 2022 (no of csfb larvae/10 plants)
Plot 1	NACRE Vetch Bingo Vetch Phacelia Fenugreek Linseed	5.0 kg/ha 2.0 kg/ha 1.0 kg/ha 2.0 kg/ha 2.0 kg/ha	97
Plot 2	Buckwheat NACRE Vetch Phacelia	5.5 kg/ha 5.0 kg/ha 1.5 kg/ha	52
Plot 3	None – (control)		149
Plot 4	Spring beans	10 plants/m^2	138

Table 6. Stem larvae numbers in adjacent areas with and without companion crops, Shropshire December 2022.

Stem larvae counts, Shropshire December 2022 (no of csfb larvae/10 plants)		
Site 1, large plot in centre of field	OSR	66
	OSR + diverse companion crop	11
Site 2, 24m strips	OSR	186
	OSR + diverse companion crop	99
Site 3, 24 m strips	OSR	46
	OSR + diverse companion crop	6
Site 4, 12m strips around headlands	OSR	134
	OSR + diverse companion crop	48

Biomass samples were taken in the Cambridgeshire companion crop trial before harvest but the small sample areas possible, meant that the results were inconclusive. Yield data were obtained from one commercial combine harvester. Analysis of the data showed that there was a yield deficit from the companion crop at site 2 (Figure 10). This site had high csfb larval numbers. The phacelia appeared to be too vigorous and may have created crop competition (Figure 9). Further work is required to understand how best to manage competition between the companion crops and the OSR through seed rates and subsequent management (e.g. herbicides, mowing etc).

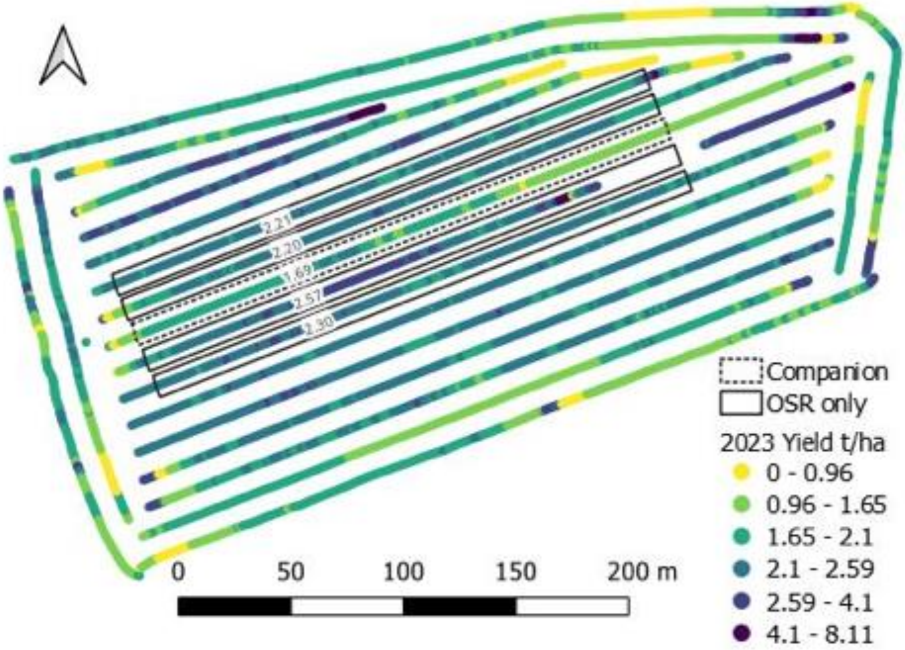


Figure 10. Cleaned yield data obtained from the combined yield-mapping from the Site 2 companion crop trials in Shropshire, July 2023.

3.7 Develop and evaluate methods for monitoring emergence of csfb adults from the soil.

Alford (1979) carefully documented the timing of the appearance of csfb adults in stubble fields and their movement into new OSR crops. The methodologies used to catch or trap the csfb adults often involved the use of nets, or suction traps and more latterly, sticky traps. Historically the time when csfb adults are damaging the new crop (early September) has been described as the "migration" of csfb adults after they have emerged from the soil in late spring and have then "aestivated". However, with the methods used, it is not possible to determine whether the csfb adults had just emerged from the soil or if they had all left the soil much earlier in the year but had remained in the locality.

Throughout the first autumn and winter (2020-21), many discussions were had with growers in the csfbSMART network, which led us to consider whether there was a stronger link to the vicinity of the previous crop, when damage occurred, and less to the number of csfb adults seen at harvest. To this end, a limited number of insect emergence traps were located and deployed throughout the autumn of 2021.

This task aimed to more accurately determine where and when the csfb adults emerge from the soil using insect emergence traps. Such traps are fixed to the ground and physically caught any insects emerging from soil (including csfb adults) at the point soon after they leave the soil.

Methods:

Initially we used emergence traps constructed with steel frames covered with nets. These were deployed in pilot trials in 5 fields after OSR harvest in 2021; the traps were monitored approximately weekly. During the pilot we found that the nets very quickly deteriorated with strong winds, pecking birds and other insects.

In 2022, we received additional funding that allowed the roll-out of traps constructed with stainless-steel mesh. The traps are conical with a water trap on the top in which the csfb adults become trapped (Figure 11). This allowed monitoring on a regular basis without any disturbance to the traps. Traps were successfully deployed after harvest in 2022 at eight sites around the UK in areas with moderate and high levels of expected csfb populations.

In 2023, they were deployed both before and after harvest into fields that had been selected following collection of OSR stem samples from a range of locations and then processing the samples to find fields with high csfb stem larvae levels.

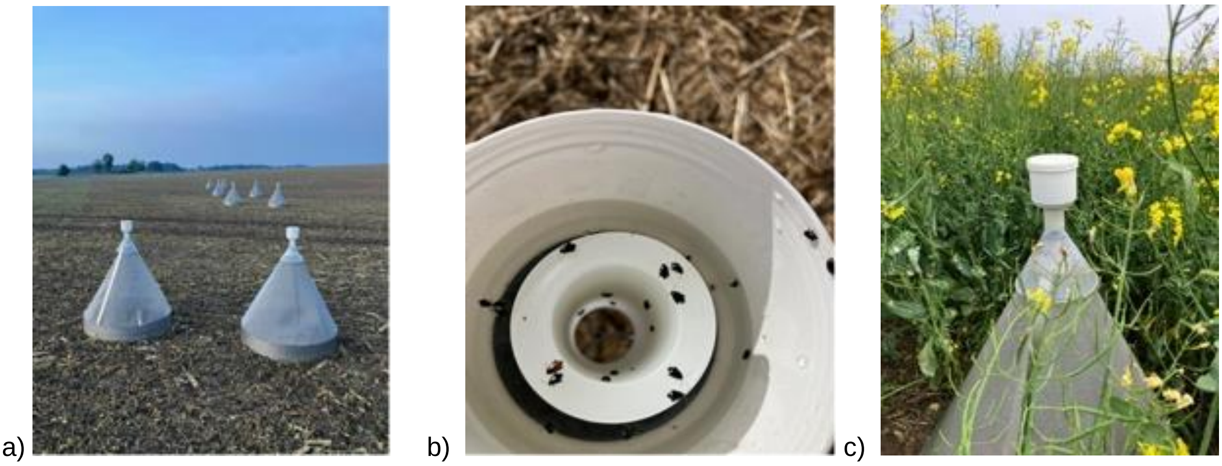


Figure 11. a) Stainless steel emergence traps deployed as part of a monitoring campaign, b) Close up of the insect water trap on the top of the emergence trap, c) Monitoring in a standing crop of OSR.

Results and Discussion:

The data collected from the small number of insect emergence traps in the late summer of 2021 seemed to indicate that csfb adults were emerging from soil during late August and into September (Figure 12). The information from the 2021 emergence traps was new and added to the information derived from the historic literature where methods were not able to specifically determine when the adults left the soil in the OSR stubble, only their presence within it and in adjacent fields.

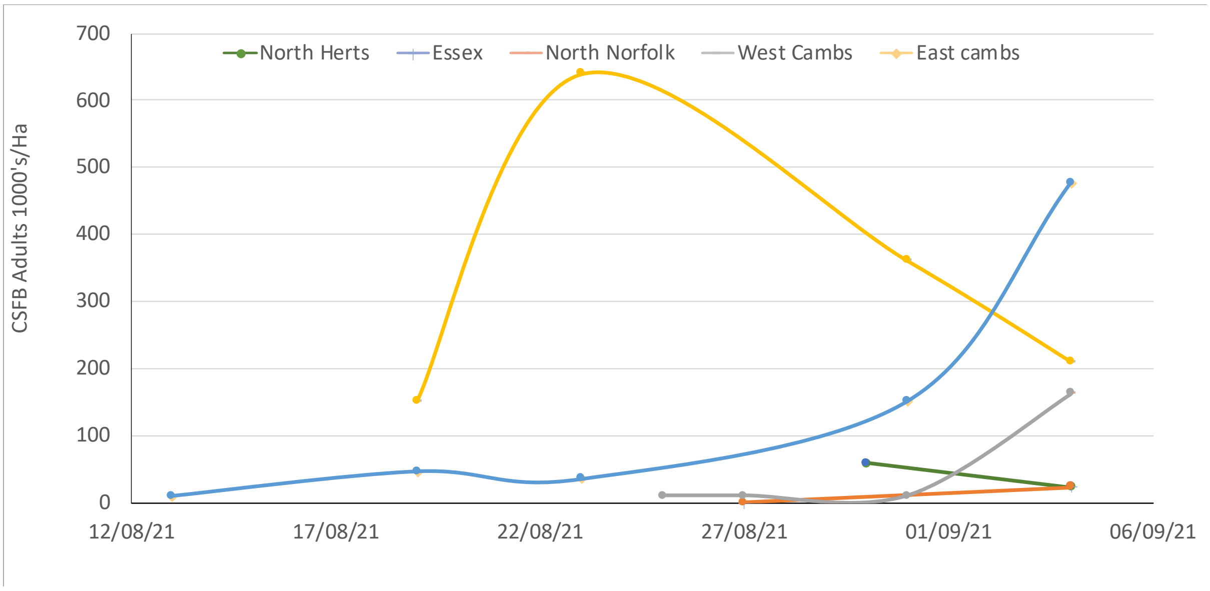


Figure 12. Emergence from the soil of csfb adults post-harvest 2021.

Despite the fact that the traps were deployed for a short time and that the netting on them soon became damaged by pecking insects and birds, it became clear that there was an emergence from the soil of csfb adults at a later time than the literature suggested previously, suggesting that this was an area that needed to be investigated further.

In 2022, eight sites in OSR stubble were monitored from August to early November. In the areas in the West and North, where moderate levels of csfb populations were expected, the numbers of csfb adults emerging from the soil, although variable at each site, were significant through the late summer season (Figure 13).

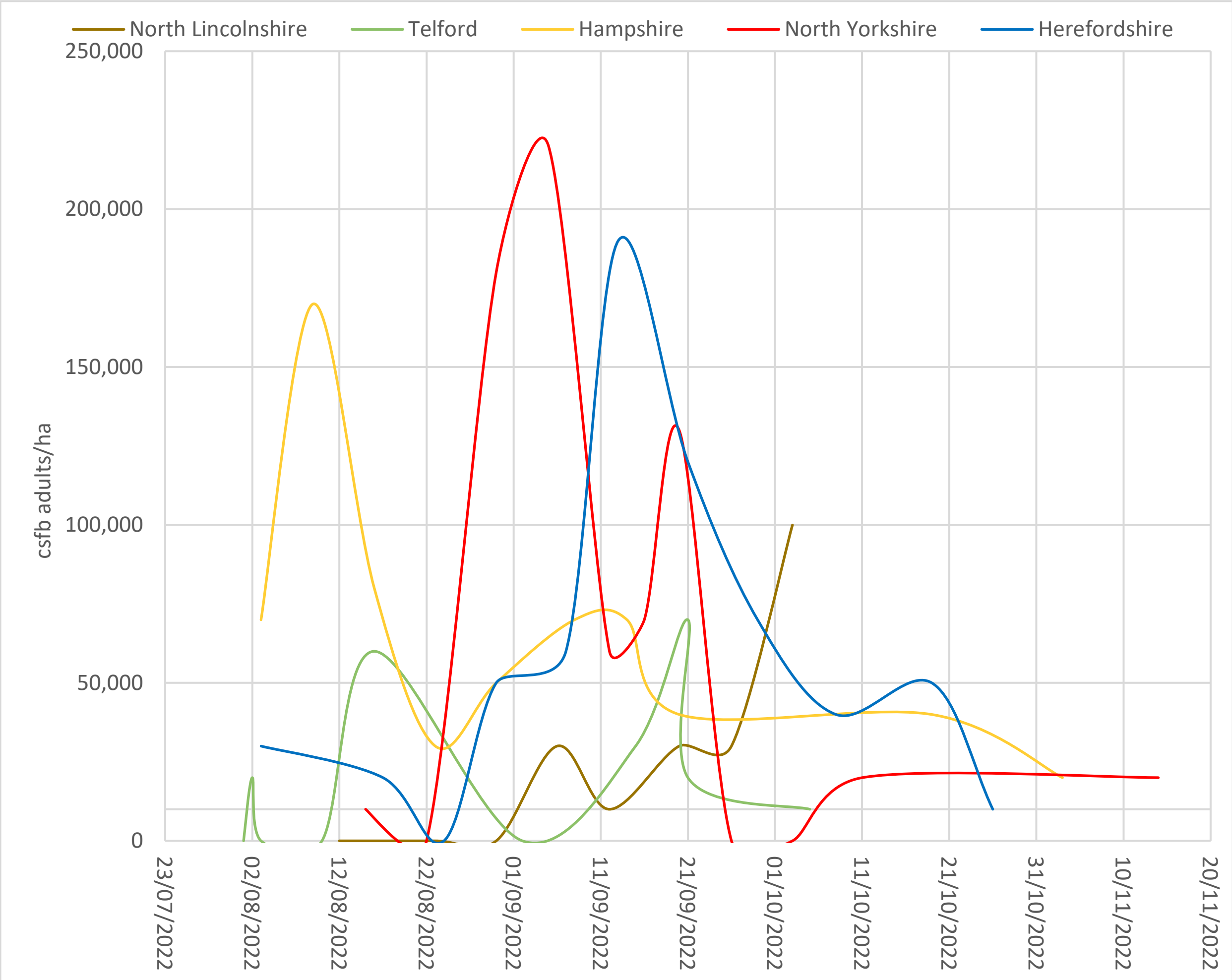


Figure 13. Numbers of csfb adults recovered from emergence traps (no/ha) at five sites where regional pressure is relatively low in the north and west of England, summer - autumn 2022.

In the areas where the highest csfb populations were expected, three sites were monitored. In Cambridgeshire and Hertfordshire, the emergence of csfb adults from the soil in mid-September peaked in excess of 700,000 csfb adults/ha in the space of little more than a week (Figure 14).

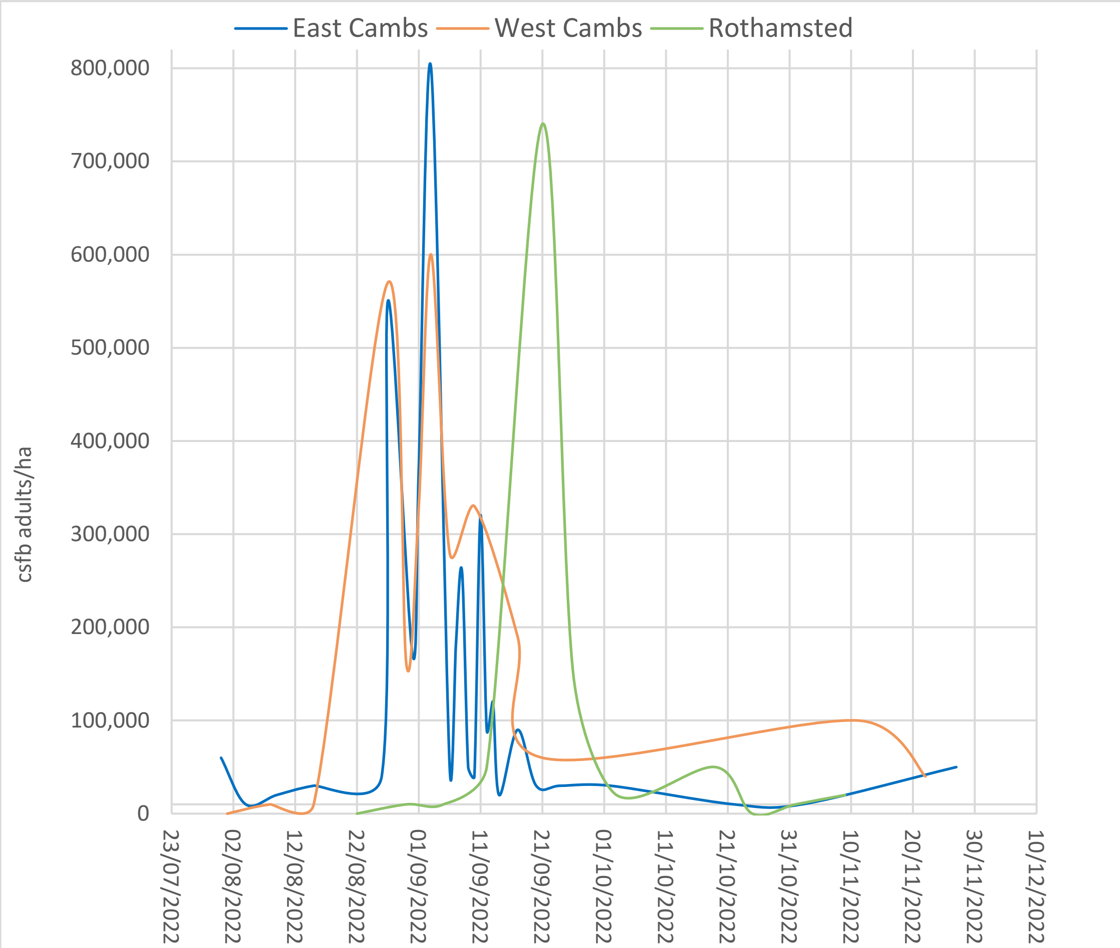


Figure 14. Numbers of csfb adults recovered from emergence traps (no/ha) at three sites where regional pressure is relatively high (Rothamsted, Hertfordshire; 2 farms sites in Cambridgeshire) summer 2022.

In 2023, two sites, one in Shropshire and one in Hertfordshire, had emergence traps set up in the standing crop of OSR prior to harvest. This was the first year that the traps were available early enough for this to happen and results showed that the equivalent of 2.45 million csfb adults/ha emerged from the soil in Shropshire from early June to mid-July which was several weeks prior to any emerging in Hertfordshire where only 190,000 csfb adults/ha emerged before mid-July. Figure 15 shows the two different emergence patterns from both sites highlighting the earlier emergence on the Shropshire site. It is interesting to note that at both sites, the numbers reduced to almost zero, prior to the crop being harvested. After harvest, the traps were put back in the same place where they then recorded the number of csfb adults emerging after harvest (Figure 16).

Overall, the emergence data collected clearly demonstrate that whilst there may be a late spring emergence, csfb adults are still emerging from the soil in August and through September. This suggests that there may be csfb pupae still in the soil at and after OSR harvest. This may provide an opportunity for development of an IPM strategy targeting this vulnerable stage (Figure 17).

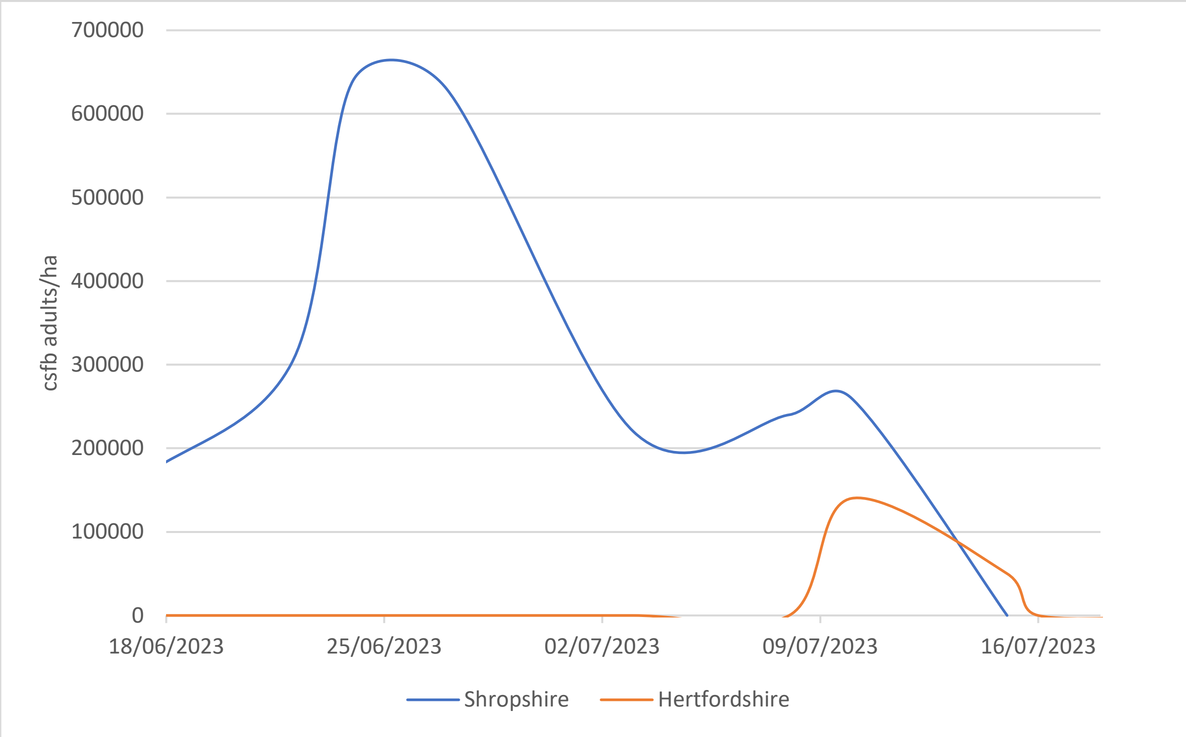


Figure 15. Emergence of csfb adults in 2 standing crops of OSR, late spring 2023.

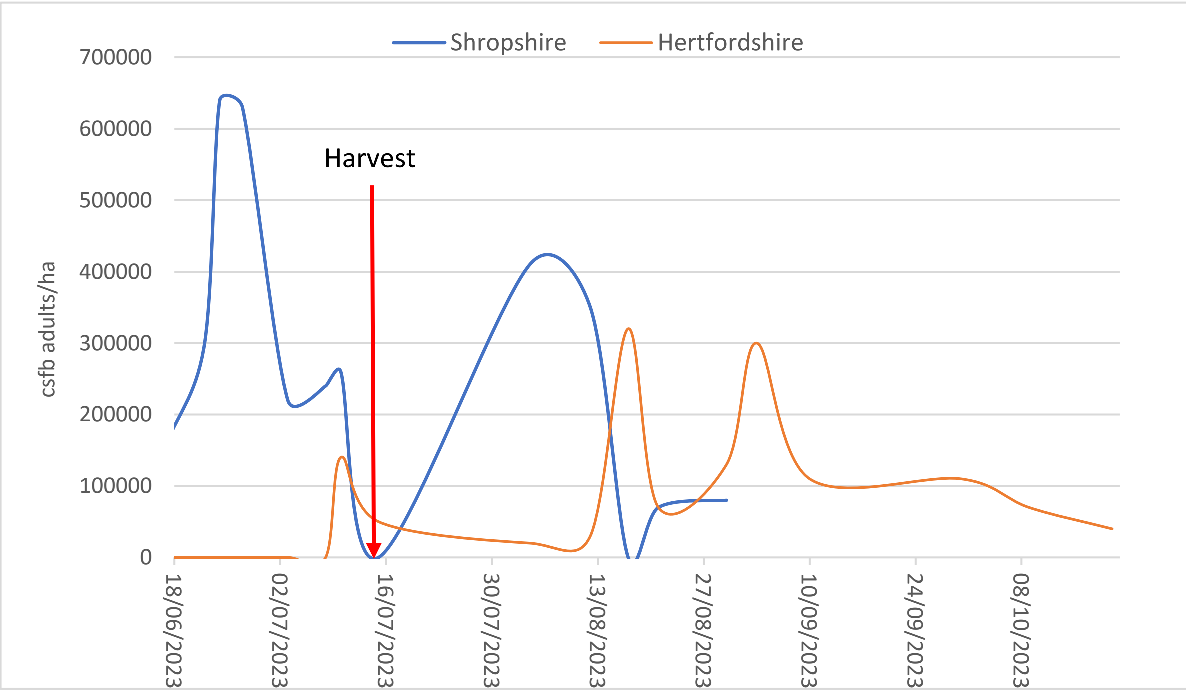


Figure 16. Emergence of csfb adults at 2 sites before and after harvest, late spring 2023.

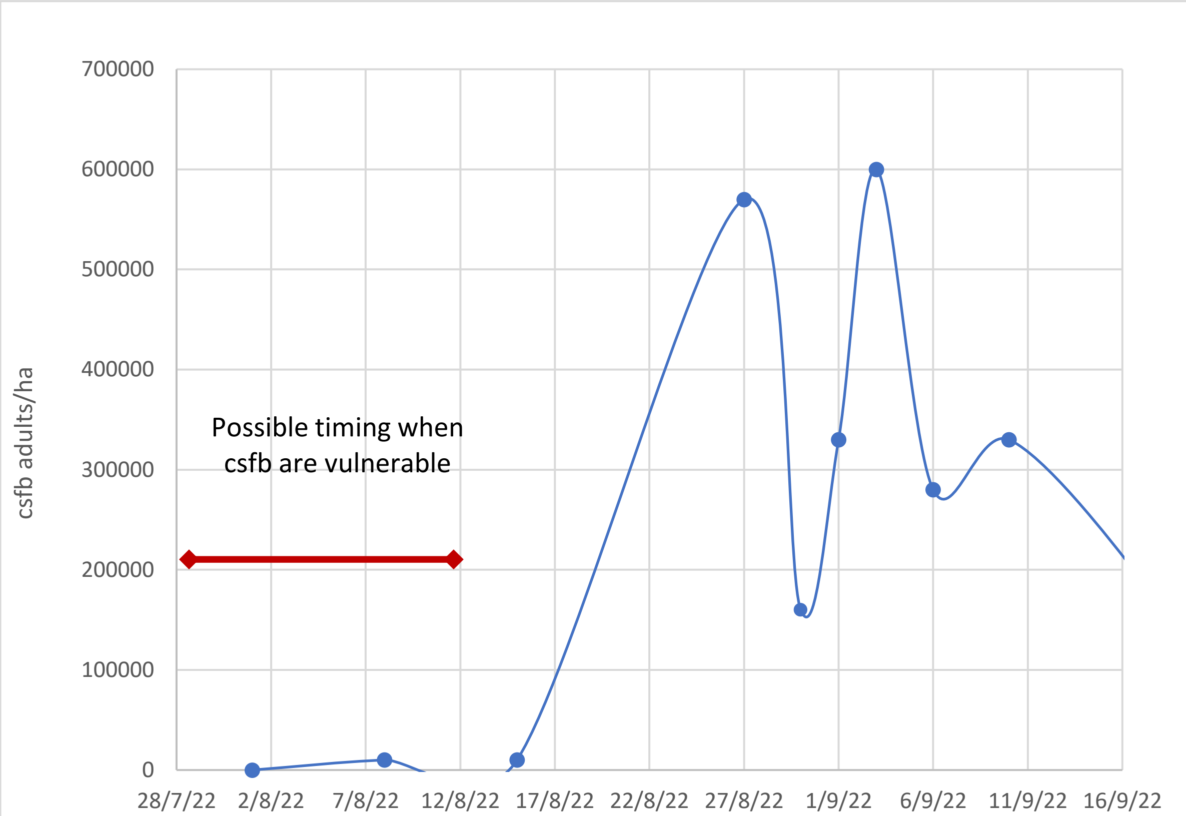


Figure 17. Emergence data for a Cambridgeshire site (after harvest 2022) showing the timing where the csfb pupae may be vulnerable to control.

3.8 Evaluate the impact of methods to control emerging CSFB adults using cultivations.

The evidence from this project shows that some of the population of csfb adults regularly emerge from the soil at a much later date than described in the historic literature. Based on the emergence data, the simple question was: If there are vulnerable stages of this pest in the soil after harvest, can cultivations be used to reduce the numbers of csfb adults emerging from soil?

This task aimed to establish a pilot study in 2022 to test the hypothesis that cultivations reduced the number of csfb adults emerging from the soil. Following the success of the pilot, a second series of experiments was carried out in 2023.

Method:

In 2022, two sites were selected to test whether post-harvest cultivations in OSR stubble reduced the numbers and/or changed the pattern of emergence of csfb adults. Both sites were in Cambridgeshire, (East and West) and were known to have high levels of csfb larvae in the previous crop.

On the East Cambridgeshire site, cultivations were very shallow (50 mm), and were carried out by a standard disc cultivator with a packer-roller.

On the West Cambridgeshire site, deeper cultivations were carried out (250 mm) using a subsoiler which also had a packer-roller fitted.

Emergence traps were used to monitor the difference in csfb adult emergence from uncultivated and cultivated areas. The emergence traps were monitored on a weekly basis throughout the summer and into early autumn.

Locating sites for trials in 2023 was very time consuming, as we only had sufficient traps for a limited number of sites, only sites with very high numbers of stem larvae were suitable and this involved collecting a large number of stem samples in December 2022; possible sites were then revisited to check on the stem larvae status later in the winter. Figure 18 shows the number of larvae present in ten plants on one of the Hertfordshire sites.

Initially sites were planned in the south based mainly in Hertfordshire and Cambridgeshire where csfb numbers are generally much higher. However, the intense cold weather of late winter 2022-23 had a devastating impact on many of the crops that were struggling with high numbers of stem larvae on the previously identified sites and some of these crops failed. Further sites were identified in Shropshire with high numbers of stem larvae, but where the weather had been less damaging in the winter. After this site selection process, five trial sites were established: two sites were set up in Hertfordshire, one in Essex and two in Shropshire. One of the Hertfordshire sites was set up at Rothamsted on a small trial area of oilseed rape, but the numbers of csfb adults emerging were too low on this site to give sufficient data. Hence only four sites are able to be reported in full for 2023.

Figure 18. Stem larvae from 10 oilseed rape plants from a potential trial site in Hertfordshire.

Cultivations were carried out using locally available equipment. The target was to cultivate at two different depths, namely 50mm and 250mm. On two sites, there was an additional treatment of a “straw rake” (Figure 19) which is a very shallow operating tool often used to gently cultivate the soil surface to help “chit” weed seeds after harvest. On the Essex and Shropshire sites, standard disc cultivators were used (Figure 20), on the Hertfordshire site, a Terrastar cultivator (Figure 21) was used which has a very different mode of action as it “plucks” at the soil surface, rather than cuts and compresses like the disc cultivators.

Figure 19. A straw rake being used on the Shropshire site.

Figure 20. A standard disc cultivator.

Figure 21. Terrastar Cultivator.

Emergence traps were deployed on the cultivated plots as well as on an uncultivated area (Figure 22). Monitoring took place roughly weekly from cultivation until drilling of the next crop a duration of at least 8 weeks.

Figure 22. Insect emergence traps on cultivated and uncultivated soil.

Results and Discussion:

In 2022, the pilot study found that there was a significant difference in the numbers of csfb adults emerging where cultivations were carried out.

At the East Cambridgeshire site, the emergence from the soil of csfb adults was reduced by over 90% (Figure 23).

On the West Cambridgeshire site, the emergence of csfb adults was reduced by 68% (Figure 24).

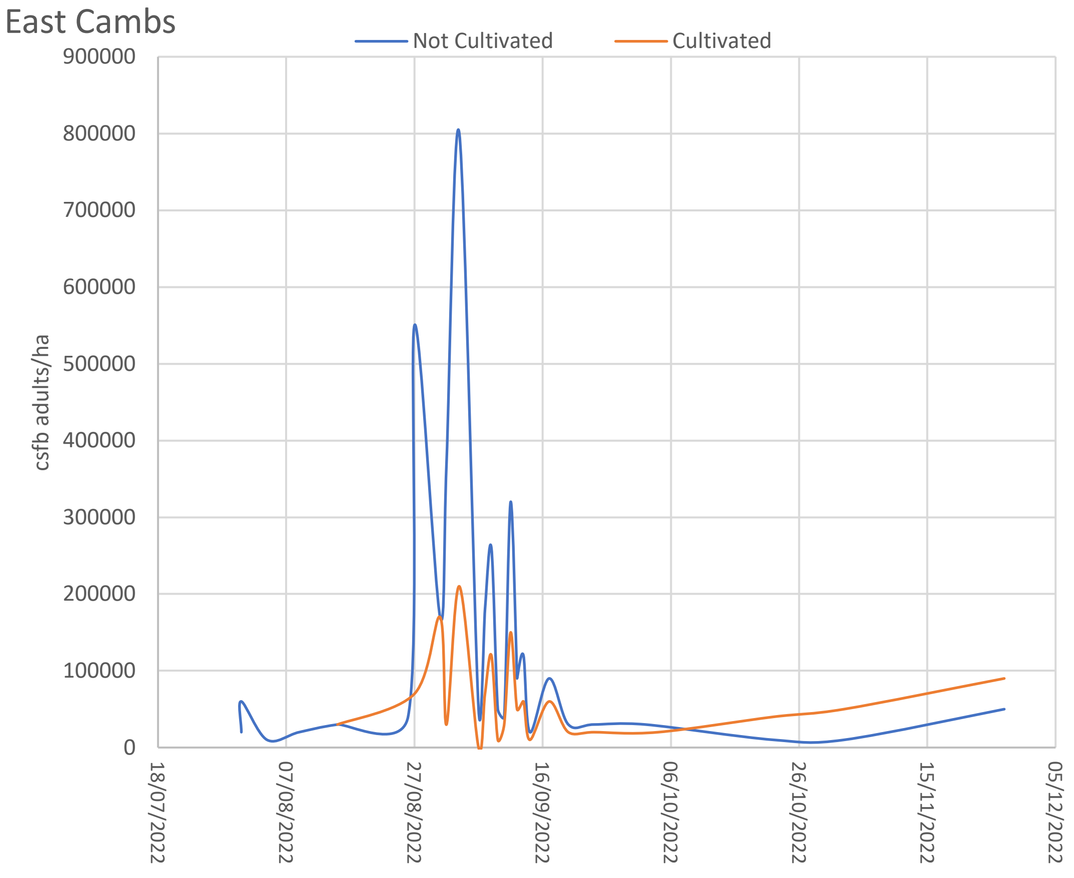


Figure 23. Emergence counts of csfb adults from cultivated and non-cultivated soil at the East Cambridgeshire site in 2022.

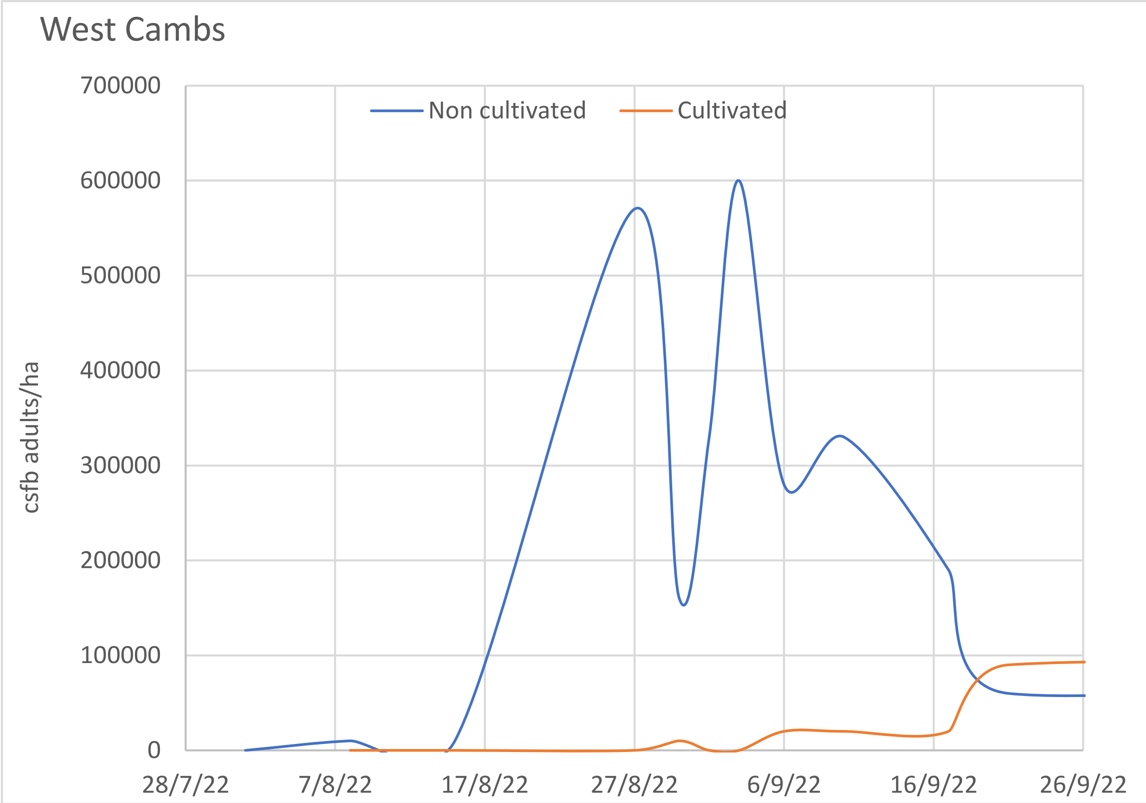


Figure 24. Emergence counts of csfb adults from cultivated and non-cultivated soil at the West Cambridgeshire site in 2022.

In 2023, at the four sites where the treatments were able to be applied and monitored, there was a marked reduction in the number of csfb adults emerging from the soil where the soil had been cultivated (Figures 25-28. Cumulative totals are shown in Table 7.

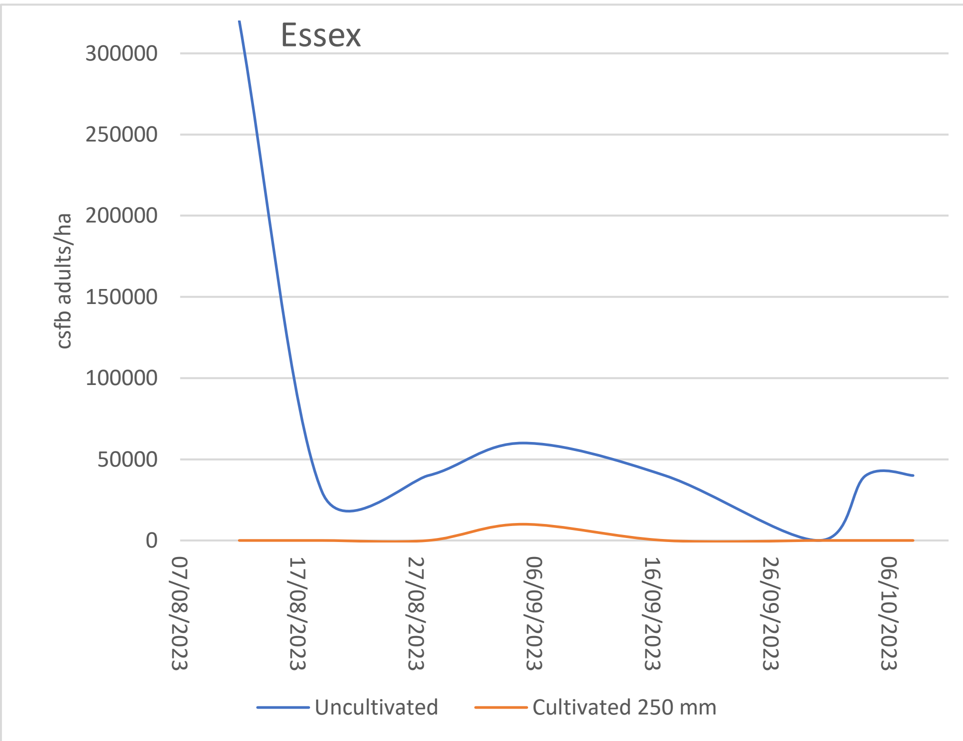


Figure 25. CSFB adult emergence counts from cultivated and non-cultivated soil Essex 2023.

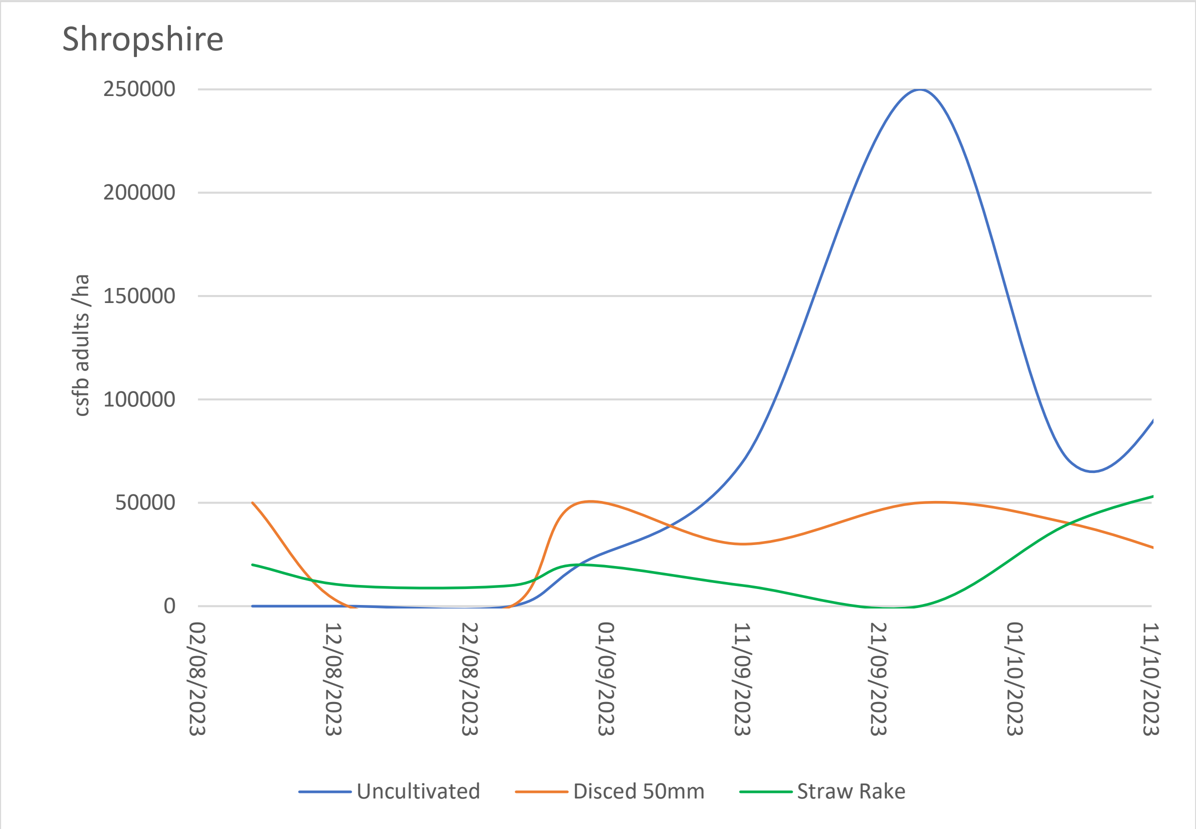


Figure 26. CSFB adult emergence counts from cultivated and non-cultivated soil Shropshire 2023.

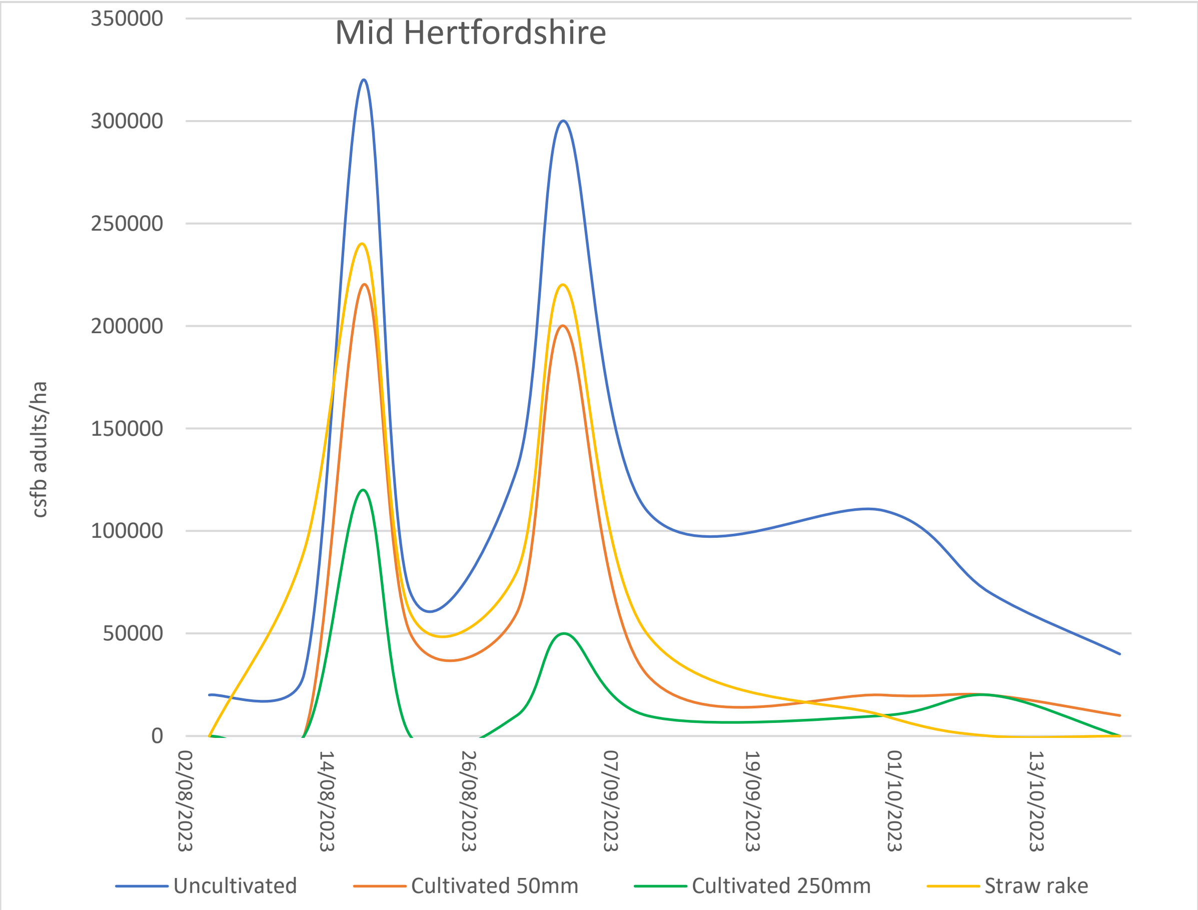


Figure 27. CSFB adult emergence counts from cultivated and non-cultivated soil Hertfordshire 2023.

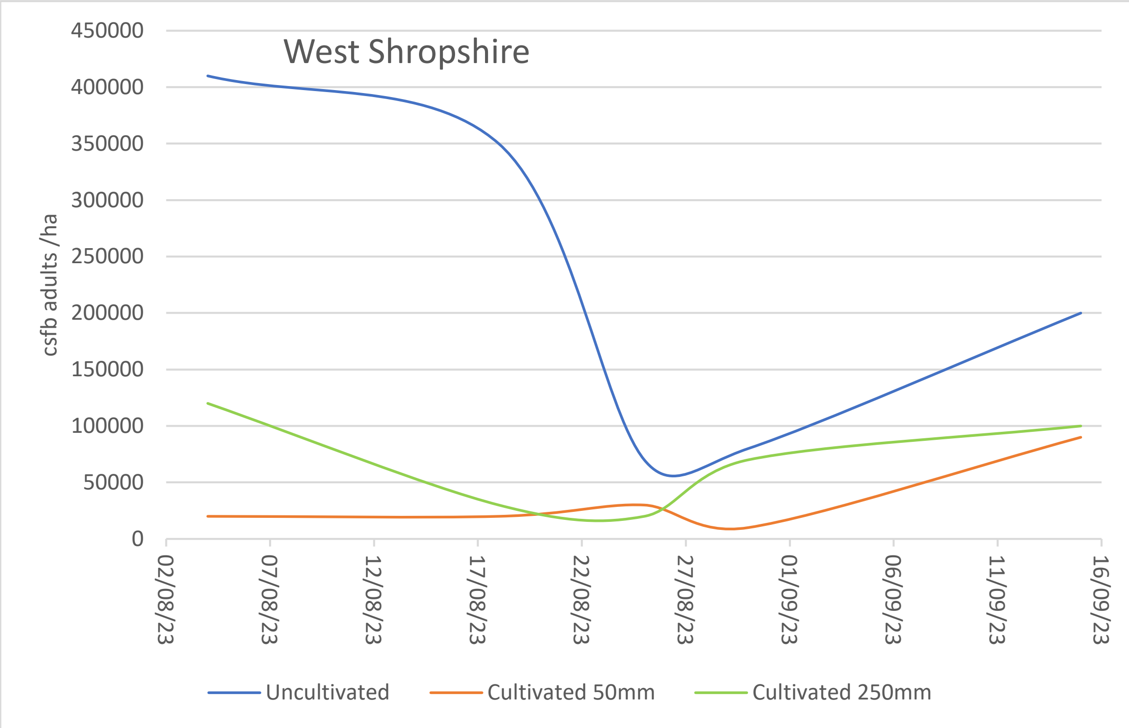


Figure 28. csfb adult emergence counts from cultivated and non-cultivated soil West Shropshire 2023.

Table 7. a) Cumulative totals of csfb adult emergence from cultivation trials in 2023 and b) percentage reduction of csfb adults emerging.

a) Numbers of csfb adults/ha after harvest.

Cultivation depth	Uncultivated	Shallow (straw rake)	50mm	250mm
Essex	57000	*	*	1000
Hertfordshire	120000	75000	61000	22000
Shropshire	54000	17000	24000	*
West Shropshire	110000	*	17000	34000

b) Percentage reduction from uncultivated

Cultivation depth	Shallow (straw rake)	50mm	250mm
Essex	*	*	98
Shropshire	37.5	49	82
Hertfordshire	68	56	*
West Shropshire	*	85	69

* cultivation not carried out.

The results clearly show that there is a reduction in the number of csfb adults after cultivating the stubble of oilseed rape soon after harvest.

There are differences in the success rate of different cultivators and is likely to relate to soil type and soil moisture. The straw rake used on the Shropshire site was more effective than the same cultivator used in Hertfordshire as the soil in Shropshire has a higher sand content and was moist when cultivated meaning that the cultivator penetrated much deeper at this site than the very dry and heavy clay on the Hertfordshire site. At this point, we have little knowledge as to what is actually happening within the soil and how this is affecting the csfb numbers which also means that we do not have information relating to how this cultivation is affecting other flora and fauna within the soil.

As this cultivation was carried out soon after harvest, the growth of the oilseed rape volunteers was not affected and as such, a canopy on all the sites was rapidly established therefore not affecting any potential benefit that is suggested by having the volunteers as a catch crop to assist with reducing adult feeding damage on the new crop (White *et al*., 2020).

3.9 Develop and evaluate methods to monitor the development of csfb larvae in semi-controlled conditions.

Research within this project (see Section 3.7) indicated that csfb adults are found in emergence traps throughout the summer. The emergence of adults from the soil continues through September into early October. The current lifecycle description suggests that the adults leave the soil in late May, therefore it is unclear what is happening. The simplest explanation is that a subset of the population develop more slowly and remain as pupae through summer in the soil. If this is the case, pupae should be present in the soil during the summer period, including after OSR harvest.

This task aimed to understand the development time of csfb larvae from late instar, through pupation, to adults, in controlled environments, specifically tracking the percentage at different life stages from spring into summer, to understand whether non, few, some or all emerge from the pupa (eclose) as adults by the expected date (end of May) and by harvest (mid-July typically).

Method:

Flowering OSR plants were collected from fields in Shropshire and Hertfordshire in April and transported to NIAB East Malling. Stems of the OSR plants were cut into smaller sections c. 20 cm long and laid out over damp compost in propagators. These were left for up to 2 weeks for larvae to emerge, with the first population collected after 1 week.

Thirty-three buckets were prepared with a minimum of 5 cm depth of standard general-purpose compost (nematode-free) per bucket moistened with water. Buckets were labelled with codes, specifying geographical source of the larvae and replicate number.

Standardised numbers of larvae and pupae were counted into each bucket, with a typical allocation being 14 larvae and 2 pupae (16 individuals total; Shropshire plant material had a higher % of pupae, whereas Hertfordshire material had very few pupae and so more larvae were introduced). Two rounds of introductions took place, on 15/05/2023 and a week later on 22/05/2023 as more larvae and pupae were obtained from the plants. Buckets were covered with fine nylon mesh to reduce escapes and most were kept at 17°C and in 12:12 D:L conditions.

10 buckets (all insects from Hertfordshire as these were more numerous, 5 from the first-round introductions and 5 from the second round) were kept outside under ambient conditions, covered by mesh and plastic sheeting to stop the contents flooding in heavy rain. They were checked at least weekly for moisture levels, and if the compost in the buckets overall was visibly dry, all were moistened with 300 ml water per bucket per week.

At points over the oilseed rape growing season (generally fortnightly), buckets were randomly selected from those held indoors and outdoors, set up in first or second wave, and the two source locations. Selected buckets (2-3 per timepoint) were ‘sacrificed’ and the contents checked.

Flotation is a methodology that is used widely by entomologists to extract pupae or cysts from soil samples (e.g. Barker and Addison, 1989). The compost or soil was placed in shallow plastic trays, 40 x 40 x 7 cm. It was crumbled gently into the base, then cold water added. As the mixture settled, larvae, pupae and adults floated to the surface. The tray was covered during the settling phase to prevent escapes. The soil and water were left overnight for insects and other organisms/organic material to float to the surface; the tray was covered by plastic sheeting to prevent bird predation or adult escapes. Again, the surface was checked for csfb larvae/pupae which were collected. The soil/compost was then re-agitated once more and allowed to settle for a further c. 4 hours. After a final check (again, with collection), the sample was considered processed.

Total number of insects (larvae, pupae, adults) from each bucket were recorded and compared with the number introduced. Where the identity of an organism was unclear, it was placed in a clean petri dish and taken to the lab for microscopic identification.

Results and Discussion:

On 30/05/2023 when conventional literature indicates adults should be emerging (Såringer, 1984), three buckets were sacrificed (two from the first-round setup – 15 days from experiment start – and one from the second-round setup – 8 days from experiment start) and 23.6 ± 6.0% of the original larvae/pupae were retrieved from the selected buckets (2-5 individuals per bucket). Of these, insects from buckets set up in mid-May were 60-100% pupae whereas the bucket set up a week later only contained a single pupae and the others were still larvae. After 4 weeks from initial set-up, no living larvae or pupae were retrieved and as no csfb at any life stage were found in any subsequent samples then the experiment was terminated on 19/07/2023.

From the outset, very low numbers of larvae and pupae were recovered from buckets.

Possibilities include:

1.The larvae (which are very mobile) migrated out of the buckets and into the wider room – the buckets were covered but not sealed tightly, to allow airflow and avoid condensation build-up. Care was taken to ensure suitable conditions (compost that was neither too dry nor waterlogged) and suitable depth for burrowing; the depth was greater than 30mm as used by many wild beetles.

2.The larvae died in the buckets, and either rotted or dehydrated, and so were not detectable via flotations.

Overall, as the retrieval rate was so low, it was not possible to deduce additional information about the development of the larvae using this method. A different approach could be attempted in a future trial. A suggested protocol is: use topsoil as the substrate and add the larvae to this substrate in smaller containers (e.g. 1 litre) with a sealed but ventilated lid (e.g. ventilated lunchboxes or mason jars with filter paper lids sealed with wax). This may allow individuals to be followed more precisely.

It is notable that even though the buckets were set up in mid-May to late-May, the majority of insects being added were still in the larval stage. Conventional literature indicates that most should be pupating by this point, to enable eclosion in late-May to early-June.

2023 was characterised by some late and very intense frosts and cold periods that affected OSR crops; this may have delayed development somewhat. However, the sampling took place from fields that were not badly affected by the frost and the plants were well established by this time.

3.10. Develop and evaluate methods to monitor the development of csfb larvae in the field.

To further explore whether csfb now also diapause as larvae or pupae in the soil over summer, and if so, where, an additional task was carried out. This task aimed to explore the development and populations of csfb in oilseed rape fields. Specifically, it asked:

- When, in the spring and summer period, is csfb present in the soil, and when does it stop being present in the soil?
- Where are csfb located in the soil (depth below the surface)?

Method:

Soil samples were collected from two sites in Hertfordshire and Shropshire.

Approximately weekly from May to October 2023, 1 litre bags of soil were filled from 2 sites (Hertfordshire, Shropshire), at depths of 0-30mm, 30-60mm, 60-90mm and 90-120mm below the surface. The soil was extracted by digging a small trench within the crop and then cutting sidewards to ensure collection of depth-stratified samples. These were transferred to a labelled Ziploc bag.

Samples were transferred to NIAB East Malling laboratories. Soil was held in a cold store until processed, and then csfb larvae, pupae and adults were extracted via flotation.

Total number of insects (larvae, pupae, adults) from each soil sample were recorded. Where the identity of an organism obtained from the soil was uncertain, it was placed in a clean petri dish and taken to the laboratory for microscopic examination.

Analysis took place in RStudio running R version (R Core Team, 2023). The package ggplot2 was used to create customised heatmaps as a visual representation of changes in life-stages in different soil layers over time. Chi-square analyses were used to compare depth preferences within each site (testing against a null hypothesis that within each site, beetles were randomly distributed by soil depth).

Results and Discussion:

Overall, more larvae and pupae were found in samples from the Hertfordshire site than the Shropshire site. Both sites had insects in the soil in good numbers to late June, and some as late as mid-July, occasional adults were found as late as the beginning of August in the Shropshire samples.

The majority of insects (Hertfordshire: 78%, Shropshire: 59%) were found in the top 30 mm of soil (Figure 29), and this was a significant pattern overall ($\chi 26 = 209.8$, $P < 0.0001$).

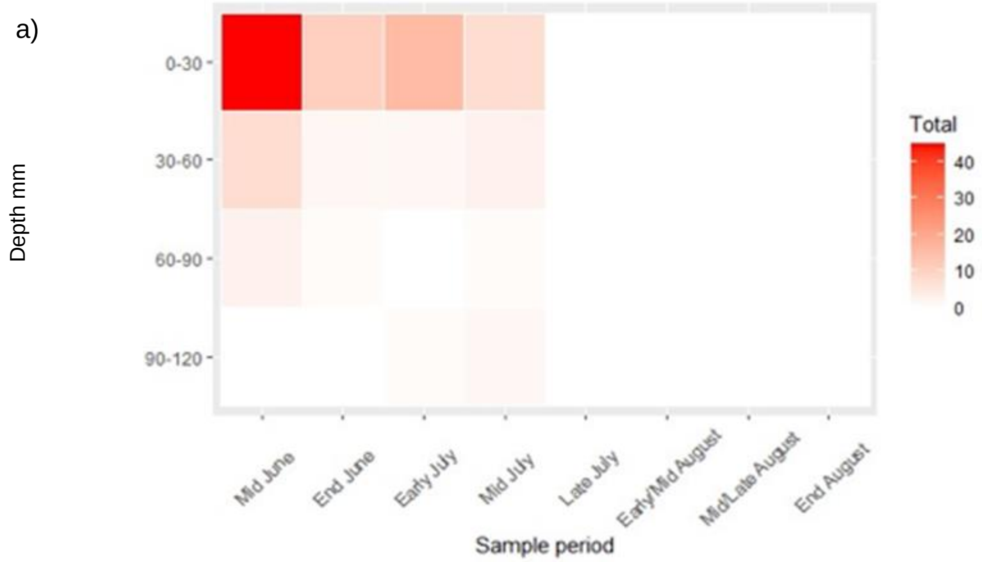
In the first floated soil samples (collected from the field in mid-June and floated on 24/06/2023), 4% of the insects found were larvae, 55% pupae and 41% adults in Hertfordshire, and 16% of the insects found were larvae, 39% pupae and 45% adults in Shropshire. Over subsequent weeks, the ratio of adults to subadults was higher in upper layers, with lower soil levels more likely to have subadult life stages if anything. Larvae were not seen beyond early July at either site (2 dead larvae were retrieved from a Hertfordshire sample taken in early July and floated on 14/07/2023) (Figure 30).

csfb larvae and then pupae were present in the soil, albeit at reduced numbers, right up until harvest in mid-July. After this point, few were recorded from both sites in the soil to a depth of 120mm.

Conversely, on both sites, adults were captured by soil emergence traps throughout the summer and autumn. It is unclear where these adults are coming from, as we found no evidence of them in the soil in this part of the year.

The majority of csfb of all life stages were found in the top 30 mm of soil. Smaller numbers were found at greater depth, but on average these were at earlier development stages. It is possible that some were at those depths due to having fallen between cracks in the soil either during the sampling process, or due to other activities in the soil. It is possible that a second population could be present even deeper, accounting for the autumn appearances in traps, but superficially no evidence is available to support this.

a)



b)

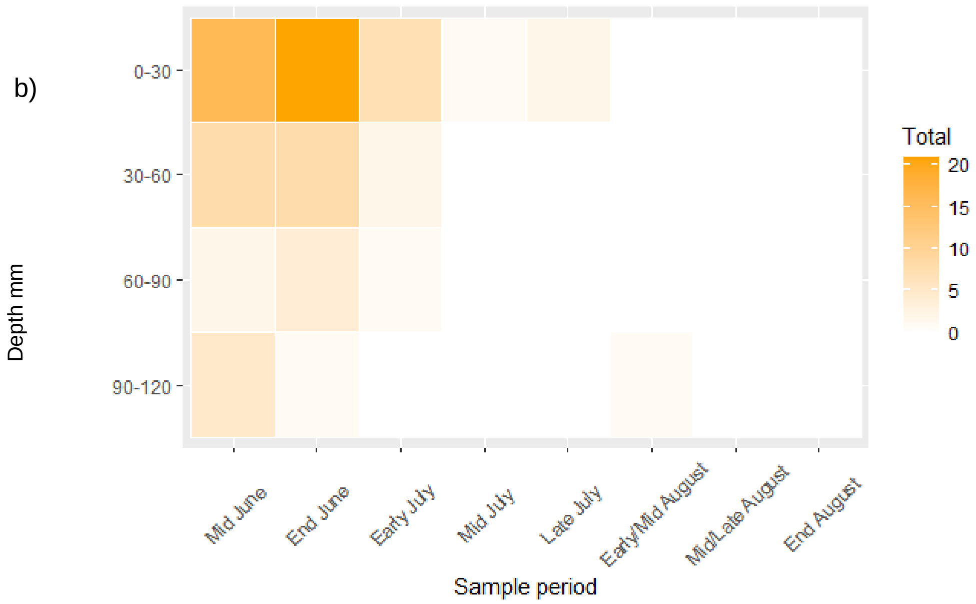


Figure 29. Heatmaps showing the number of csfb (any life stage) from (a) Hertfordshire and (b) Shropshire sites, over time and soil depth.

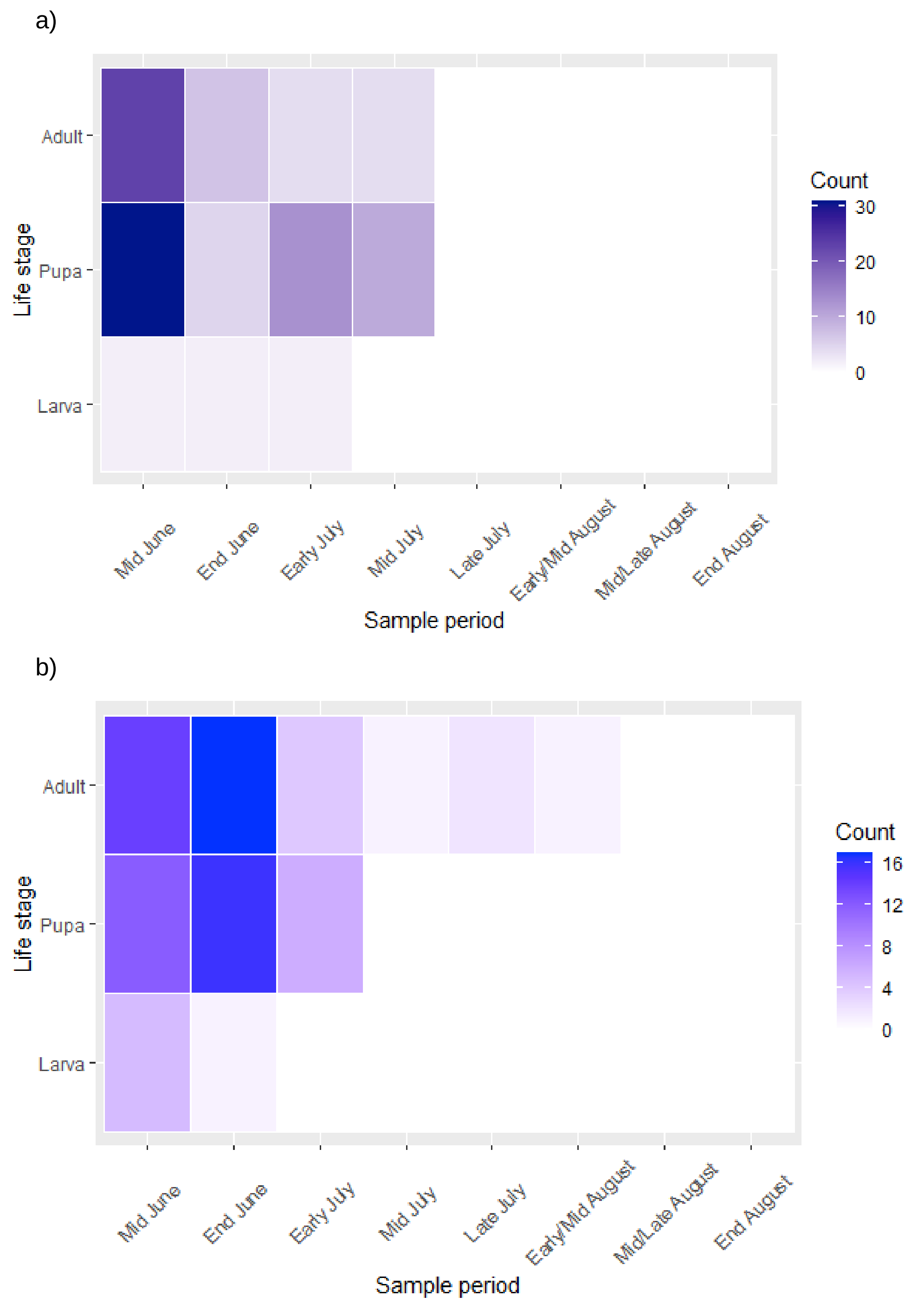


Figure 30. Heatmaps showing the numbers of csfb (from any depth) at different life-stages from (a) Hertfordshire and (b) Shropshire across the 2023 season.

3.11 Spatial distribution of Oilseed Rape Crops in relation to previous crops.

Anecdotal information gained from talking to many growers throughout the project has suggested that there may be a relationship between the proximity of the previous year's OSR and damage to current OSR crops. On several occasions in discussions with growers, it was noted retrospectively that the higher numbers of stem larvae "may" have been nearer a previous crop than the lower counts. Similar discussions have been had relating to adult feeding damage on emerging crops. This was also noted by Boetzl *et al.* (2023).

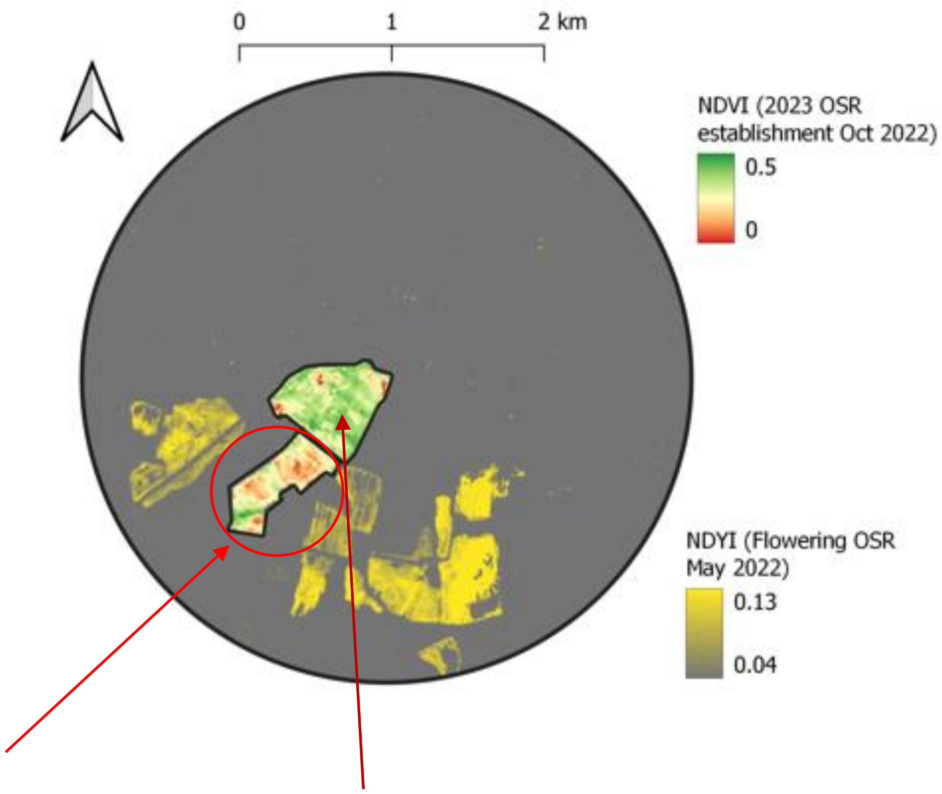
This task was a pilot study that aimed to explore whether satellite imagery could be used to look at the position of previous OSR crops within the landscape, together with data of OSR establishment and stem larvae numbers.

Method:

Satellite imagery was obtained using the UKCEH Landcover© Plus Crops sample dataset viewer and processed to identify the fields of interest and then overlay the Normalized Difference Vegetation Index for October 2022 to show establishment variation in OSR alongside the Normalized Difference Yellow Index for May 2022 showing location and crop vigour at flowering of previous OSR crops.

Results and Discussion

Figure 31 shows the processed satellite imagery of the site in Hertfordshire used for the cultivation and emergence work in 2023, overlaid with the location of the previous years oilseed rape crops shown in yellow; much of this OSR was on a neighbouring farm. The levels of stem larvae to the north side of the field where the emergence work was carried out were very high. The field, circled in red, was a crop failure due to a combination of adult damage at establishment and the level of stem larvae in late winter suggesting that the areas nearer the previous crops were subject to higher levels of csfb damage/pressure. These data suggest that further use of this methodology to study the position of previous crops, linked to data of OSR establishment and stem larvae numbers, may allow the local spatial determinants of csfb damage to be investigated at landscape scale.



Failed crop

Location of the site used for cultivation/emergence trapping work in 2023

Figure 31. Processed satellite imagery of the Hertfordshire cultivation and emergence trial site showing the position of the previous years' oilseed rape crops.

4 Implications

4.1 Changing understanding of the csfb lifecycle.

The life cycle as it is presented in conventional literature before this study took place is:

- ↓ Adults emerge from pupae and feed on foliage (Jun–Jul).
- ↓ Adults 'rest' in moist, sheltered places (Aug).
- ↓ Adults migrate into crops, feed on leaves and mate (Aug–Sep).
- ↓ Adults feed on leaves and lay eggs (Sep–Dec).
- ↓ Eggs hatch and larvae feed if temperatures are 3°C or warmer (Oct–Feb).
- ↓ Larvae feed on main stem behind the growing point (Mar–Apr).
- ↓ Larvae drop to the soil and pupate (May).

This project highlighted that this understanding is incomplete. In particular, this research project has shown:

- Csfb adults appear from the soil after harvest (Jul-Nov).
- There is some geographical variation in the timing of csfb emergence in the years of this study.
- Methods to extract pupae and larvae from soil samples need further development and evaluation.
- Proximity of the OSR crop to the previous year's crop may be important.

Gaps in knowledge identified:

- The subterranean lifecycle of csfb is relatively poorly understood; in particular more studies are needed to understand when/why the adult csfb hatch from pupae and emerge from soil.
- What triggers csfb adults to emerge from the soil: weather conditions, soil moisture, soil temperature?
- What proportion of the csfb adults emerging pre-harvest are feeding and/or egg laying in the new crop? This has implications for the monitoring of adults pre-harvest.
- Does soil sampling at harvest have a place in forecasting levels of csfb in the soil and does this link to the risk of damage to new OSR crops?
- Is the flotation technique used for the extraction of csfb pupae robust and reliable for use in research and/or on-farm?
- The factors affecting movement of adult csfb from oilseed rape stubble (possibly via aestivation sites) to the new OSR crop, both before and after harvest.

Practical implications:

- Updated understanding of the csfb lifecycle changes the way in which the risks to new OSR crops are assessed and also identifies new opportunities for control of csfb as part of an IPM strategy.
- There is potential to reduce the adult population using targeted post-harvest cultivations as part of an IPM strategy (see below). A greater understanding of the csfb life cycle around the time of hatching and emergence is needed to develop this strategy further.

4.2 Development of tools/networks for on-farm monitoring to inform practise.

The csfbSMART network was successful in bringing together farmers, agronomists and others to share information. Many "easy to use tools" have been developed in this project and by the wider science community to support monitoring of csfb and the factors affecting the risk of crop damage (e.g. soil moisture at drilling). Monitoring is a key part of an IPM strategy where the information collected at key times helps farmers and advisors understand the risks of damage from csfb and then allows them to take actions to reduce risk in their farming business.

This project has highlighted that there are a number of "on farm" tools that can be used by agronomists, advisors and growers to help with decision making at critical times. In particular, this research project has shown:

- Engagement of farmers and their advisors in a knowledge-sharing network requires a clear goal shared by farmers, focussed recruitment activity and on-going active management.

Farmers are most likely to stay engaged where they feel that their business benefits directly and immediately from their participation.

- Rapid/real time data collection from farmers and advisors using digital tools can be a useful tool to collect, geocode, collate and share information in real time.
- A range of methods are needed to understand the status of the csfb population in any given region each year.
- Some tools can already be used by farmers/advisors to support on-farm decisions:
  - Yellow water traps
  - Stem larvae assessments
- Insect emergence traps have proved critical in extending our knowledge of the csfb lifecycle and will continue to be important research tools but are currently too costly and lack accepted thresholds/links to management action to deploy routinely on-farm.
- Satellite imagery can be used post-hoc to map OSR crops in the landscape. Where this is coupled with measured patterns of crop damage, then such tools could be used to increase understanding of the spatial determinants of the movement of adult csfb.

Gaps in knowledge identified:

- Although csfb stem larvae assessments can be made simply on-farm, there are currently no thresholds to help guide decision making e.g. whether to terminate an OSR crop in favour of an alternative spring crop, expected yield impacts to allow in-season programmes of fertiliser/plant protection products to be adjusted. More information is needed to link csfb stem larvae assessments to impact on crop yield and if/how this can be modified through crop management.
- A greater understanding of the csfb lifecycle will increase opportunities to develop new targeted monitoring tools (e.g. soil sampling) that can help growers make time critical decisions that reduce risk for the OSR crop.

Practical implications:

- The use of monitoring tools has most value when applied and co-ordinated at and beyond farm-scale. Agronomists have a key role in supporting deployment and sharing information at regional scales.
- Using simple online tools to help share information within the farming industry has proved to be a useful tool but such networks require management to maintain engagement; however, a solely commercial value proposition for such networks is difficult to establish unless linked to application of plant protection products.

Policy implications:

- Rapid/real time data collection from farmers and advisors using digital tools that provide policy-relevant information is possible but is not cost free. Farmer-levy funding has traditionally played an important role in developing and supporting such networks, but it would be timely to explore a range of public-private partnership models together with the data ownership and sharing models needed to underpin such approaches whether for pests, or other environmental outcomes.
- The use of monitoring tools as part of IPM strategies is recognised within the SFI as part of IPM1: Assess integrated pest management and produce a plan. Active participation by farmers in monitoring networks could be further recognised within the SFI framework.

4.3 Opportunities for new csfb control options within an IPM strategy

The csfbSMART network has evaluated two new csfb control options. However, care needs to be taken when drawing conclusions from these small datasets as the interactions between adult damage, larvae numbers and how these affect the success of the crop are very complex.

This project has highlighted that a proportion of the csfb population emerging from the soil, did so after harvest in each of the three seasons studied. This provides a new opportunity for control. In addition, evidence suggests that longer lasting companion crops for OSR show potential to reduce the number of csfb larvae whilst increasing biodiversity. In particular, this research project has shown:

- There is potential to reduce emerging csfb adult numbers by 50-90% using a targeted post-harvest cultivation of the previous season's OSR stubble. This has the potential to reduce the risk of damage caused both by csfb adult herbivory at/soon after establishment and loss of crop vigour resulting from csfb stem larvae.
- Longer lasting companion crops show potential to reduce the number of csfb larvae whilst increasing biodiversity.

Gaps in knowledge identified:

- More data is needed to identify the impacts of different post-harvest cultivation approaches of csfb control and to better understand wider impacts e.g. on other pests, such as wireworm and on beneficial insect populations.
- How would a post-harvest cultivation strategy for OSR work in practice? Does the cultivation replace later cultivations (for establishing cereals), what are the fuel use implications and are there impacts for a following crop.
- The subterranean lifecycle of csfb is relatively poorly understood; in particular more studies are needed to understand when/why the adult csfb hatch from pupae and emerge from soil. Such information is needed to allow cultivation depth and timing to be optimised.
- The impacts of different OSR companion plants and mixtures on csfb egg-laying on OSR and the wider impacts on insect biodiversity, together with opportunities for fertiliser reduction within the OSR crop where legumes are part of the long-lasting companion crop mixture.

Practical implications:

- Post-harvest cultivation of OSR stubble has the potential to reduce csfb adult numbers whilst still maintaining the potential trap crop benefits of OSR volunteers.
- Growing OSR with a longer-lasting companion crop mixture will need to be managed carefully to balance the impacts of crop competition with any benefit of reduced csfb stem larvae damage. This approach can also reduce financial risk (as SFI option payments are associated with companion cropping and/or multi-species cover crops).

Policy implications:

- These approaches currently fit with all the IPM elements within SFI. It is important that, going forward, SFI stays up-to-date with developments in IPM across all crops, so that SFI options continue to support, and do not obstruct uptake in the future.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Published materials generated by the project.

Open days/shows

- *Farmers Weekly* Round Table event/discussion 15/4/2021
- Cereals 2021 30/6-1/7/2021
- Limagrain OSR expert panel 6/5/2022 https://lgseeds.co.uk/?s=OSR+establishment+
- NIAB csfb and oilseed rape open day Cambridge 24/5/2022
- Cereals 2022 8-9/6/2022
- Cereals 2023 13-14/6/2023
- AHDB Monitor Farm (Wisbech) Event 27/6/2023

Press articles

- Arable industry joins together to fight cabbage stem flea beetle: *Agronomist and Arable Farmer* 10/2/2021
- *Farmers Weekly* Podcast 26/3/2021
- Living with the enemy: *Crop Production Magazine* 15/4/21
- Research on flea beetle control: *Farmers Weekly* 21/4/2021
- Hope for OSR as industry tackles challenges together: *Jane Craigie Marketing* 12/7/21
- OSR growers invited to help major flea beetle trial: *Farmers Weekly* 18/10/2021
- Learning to live with cabbage stem flea beetle: *NIAB Landmark Magazine* December 2021
- Oilseed rape is on the recovery path as spring approaches: *Farmers Weekly* 23/2/2022
- New advice on volunteers for tackling flea beetle in OSR: *Farmers Weekly* 10/1/2023
- Outsmarting the beetle: *Crop Production Magazine* 21/2/23
- Latest csfbSMART findings point to better flea beetle control: (https://cropscience.bayer.co.uk/blog/articles/2023/01/latest-csfbsmart-findings-point-to-better-flea-beetle-control)

Scientific presentations

- Royal Entomological Society, Sustainable Agriculture: From monitoring to management. Dr Sarah Arnold (NIAB) poster session 27/9/23

References (from main report sections)

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