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Cabbage stem flea beetle larval survey 2016

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CONTENTS

1. Abstract

Cabbage stem flea beetle (CSFB) larval populations were monitored using plant dissection at 24 sites in Bedfordshire, Buckinghamshire, Cambridgeshire, East Yorkshire, Essex and Lincolnshire. Sites considered to be at high and low risk of larval infestation were assessed in each county. In the main high risk sites were those where a significant level of CFB adult feeding had been reported and low risk where there was limited adult damage. Crops were monitored between February and March 2016. Data specific to the sampled fields were collected, including previous cropping, establishment method, pest pressure, insecticide use, harvest yield and the field average yield.

The aims of the project were to investigate the size and range of larval populations, their impact on yield, risk factors that might help to predict larval pressure and the effectiveness of CSFB control.

Significant differences in larval population were found between high and low risk sites and counties, with the largest populations in Cambridgeshire and the smallest in Lincolnshire and East Yorkshire. At half of sites larval populations were above the autumn treatment threshold of five larvae per plant. Between the 2015 and 2016 larval surveys, the larval population increased by 20.4% in Cambridgeshire and 131.1% in Bedfordshire (other counties were not assessed in both years). The majority of larvae (96%) were found in the petioles rather than the stem. Regression analysis found that adult feeding damage at the cotyledon and three to four leaf stage, and the number of leaves per plant were significantly correlated with the number of larvae per plant in February/March. Stepwise regression analysis found that a model consisting of adult feeding damage at the cotyledon stage, the number of leaves in February/March and their interaction was most accurate at predicting larval number in February/March (explaining 64% of the variance).

Control of CSFB at the sites monitored relied almost exclusively on applications of foliar pyrethroids, although the majority of these treatments were not deemed by agronomists to provide more than 50% control. Insecticide efficacy varied between counties. A total of 85% and 55% of pyrethroid sprays in Lincolnshire and East Yorkshire respectively were considered to give more than 50% control but less than 18% of sprays were thought to be this effective in the other counties. CSFB was also shown to be the main target for pest control, accounting for 82% of all foliar insecticide applications throughout the cropping year. The oilseed rape yield in 2016 differed from the average field yield by between +0.9 to -2.5 t/ha although at most sites (83%) yield was reduced. A significant correlation between mean number of larvae per plant in February/March and the reduction in yield was found. The results are discussed in terms of the wider challenges to CSFB control.

2. Introduction

Cabbage stem flea beetle (CSFB; *Psylliodes chrysocephala*) remains a serious and intractable problem for winter oilseed rape (WOSR) growers in many parts of the UK. Adult CSFB feed on the foliage of emerging crops and can threaten establishment. They lay their eggs at the base of plants and the larvae mine petioles from mid-October before moving into the stems. In autumn 2014 and 2015 adult CSFB damage was found to affect 41% and 69% of crops surveyed respectively (Wynn *et al.*, 2014; Alves *et al.*, 2016). Losses due to adult feeding in autumn 2014 were estimated at 5% of the national crop (>31,000 ha) (Nicholls, 2015) which, based on the five year (2011-15) average UK yield of 3.6 t/ha (Defra, 2016) and an average delivered OSR price of £270 per tonne (Nix, 2015), is equivalent to more than £30.1 million. Larvae are generally considered to be more damaging than adults and monitoring in 2015 found high populations in several counties (White, 2015). Larval populations in autumn 2014 were the largest in the seven years of the Fera Crop Monitor survey and were larger again in autumn 2015 (Crop Monitor, 2016).

There are few chemical control options for CSFB. A restriction on the use of the neonicotinoids, clothianidin, imidacloprid and thiamethoxam, was enforced by the European Commission on 1 December 2013. Prior to this, these were widely used as seed treatments to protect WOSR crops from CSFB damage. In 2015 the NFU successfully applied for a derogation allowing approximately 31,000 ha of WOSR treated with neonicotinoid seed treatments to be drilled in Bedfordshire, Cambridgeshire, Hertfordshire and Suffolk (equivalent to approximately a third of the WOSR area in these counties and 5% of the national WOSR area). Mesurol seed treatment remains available to growers but there is limited data on its efficacy against CSFB. From summer 2015 the only foliar insecticides registered for use against CSFB were pyrethroids. However, in September 2014 it was announced that knock-down resistance (kdr) (which confers reduced susceptibility to pyrethroids) was widespread in the UK, with pyrethroid-resistant beetles found in all samples tested and resistance genes occurring in 73% of individuals (AHDB, 2015; Højland *et al.*, 2015). CSFB with kdr resistance in Germany have been shown to be 24 times less susceptible to pyrethroids (Højland *et al.*, 2015). There is also strong evidence for the presence of a second resistance mechanism, metabolic resistance, in UK populations of CSFB (Højland *et al.*, 2015).

The current recommended treatment threshold for CSFB larvae is five larvae per plant in late October/early November, based on a yield response of 0.34 t/ha (Purvis, 1986). The need for treatment can be assessed by plant dissection, counting the number of leaf scars produced by larvae or by water trapping of adults. Plant dissection to count the number of larvae is usually done in an accredited laboratory by experienced staff, and is relatively time-consuming and expensive. Assessing the proportion of plants with leaf-scars (the entry and exit holes created by the larvae as they move in and out of the plant) can be done in late October/early November. Work has shown that 70% of leaves with scars is roughly equivalent to five larvae per plant in late October/early

November but the treatment threshold was set at 50% of leaves with scars to reduce the risk of failing to identify fields in which a treatment is justified (Walters *et al*., 2001). Water trapping of adults in yellow water traps is best done between early September and the end of October. Green (2008) showed that catching an average of 97 CSFB per trap during that period is equivalent to five larvae per plant in late October/early November. It is unknown whether the current five larvae/plant threshold is applicable to modern WOSR varieties and agronomic practices.

In 2015, AHDB Cereals & Oilseeds funded a CSFB larval survey in selected counties (Cambridgeshire, Hampshire, Hertfordshire, Suffolk and Surrey) (White, 2015). Counties were selected based on the adult CSFB feeding damage in autumn 2014 (Wynn *et al.*, 2014). In each county, agronomists were asked to select fields which had suffered contrasting levels of damage from adult CSFB during the establishment phase of the crop, i.e. one field with high levels of adult CSFB feeding damage ('high risk') and one field with low levels of adult CSFB feeding damage ('low risk'). Sites were monitored in February and April. The survey found larval populations above the treatment threshold in all counties except Surrey, with the largest population in Cambridgeshire (mean of 27.8 larvae per plant). Larval populations were generally related to adult feeding damage during crop establishment (as reported by agronomists) with large differences between high and low risk sites in Bedfordshire, Cambridgeshire and Hampshire. The majority of larvae were found in the petioles rather than the stems in both February and April, although the proportion in the stems had increased in April. Assessment of the presence of leaf-scarring showed that it provided a reliable and easily identifiable indicator of larval infestation. Control of CSFB at the sites monitored was solely reliant on the application of pyrethroid insecticides, although the effectiveness of these sprays was mixed. A general trend for decreasing yield with increasing larval numbers was found, although statistical analysis found that this relationship was not significant.

The overall aim of the current project was to assess the size of larval CSFB populations in 2016 in selected areas of England, their impact on yield, the effectiveness of chemical control and to improve the prediction of larval populations. Specific objectives were:

1. To assess the scale and range of larval CSFB populations in counties that experienced high levels of adult CSFB feeding damage in the autumn 2015.
2. To investigate the relationship between larval CSFB pressure and the impact on yield.
3. To determine those factors that are reliable indicators of larval CSFB pressure.
4. To investigate the effectiveness of control methods used for CSFB.

3. Materials and methods

3.1. Experimental sites

Independent agronomists from the Association of Independent Crop Consultants (AICC) identified 24 fields across six counties (Bedfordshire, Buckinghamshire, Cambridge, East Yorkshire, Essex and Lincolnshire) for the study. These counties were selected as they had the highest levels of adult CSFB damage in autumn 2015 (Alves *et al.*, 2016). The number of sites monitored in each county were proportional to the area of WOSR grown, with more sites monitored in counties with larger areas of WOSR (Table 1). In each county, agronomists were asked to select half of the sites as being at high risk and half at low risk of CSFB larval pressure.

Table 1. Number of sites monitored and area of WOSR grown in each county.

County	Sites	Area of WOSR (ha)
Bedfordshire	2	13000
Buckinghamshire	2	15000
Cambridgeshire	4	33000
East Yorkshire	4	25000
Essex	4	29000
Lincolnshire	8	63000

3.2. Plant sampling

At each site, agronomists randomly selected 25 WOSR plants at an approximately equal distance apart in a 'W' pattern across the field. Plants were carefully lifted at soil level to avoid detaching the cotyledons, or lower senescing leaves in older plants, as these may have contained larvae. All sites were sampled between 1 February and 4 March 2016. Within counties, the time between sampling different sites was as short as possible, ranging from 1 to 10 days. Plant samples were sent to ADAS laboratories for dissection.

3.3. CSFB larval populations

In the laboratory, all leaf petioles and stems of the plants were dissected and the number and location (petiole or stem) of CSFB larvae was recorded.

3.4. Site data

Agronomists were asked to complete a questionnaire for each site. This was collected to give context to yield data and help identify risk factors for CSFB. Data collected included previous cropping, establishment methods, drilling date, seed rate, proximity to previous WOSR, adult

CSFB pressure, other pest pressure and control measures. The full questionnaire can be seen in Appendix 1.

3.5. Data analyses

The numbers of CSFB larvae in different counties, at high and low risk sites and in the stem or petiole were statistically analysed using ANOVA. Regression analyses were used to determine the relationship between mean larval number and a range of agronomic factors. Each agronomic factor included in these analyses had a biological explanation for why it might be a potential determinant of larval number. Significant factors from these regression analyses were then used in a stepwise forward regression to identify the model that best explained the variation in mean larval number per plant. The impact of larval number on yield was analysed using regression analyses to determine whether a single line, parallel lines or different slopes for data from the 2015 and 2016 larval surveys best explained the relationship. All analyses were done using GenStat®.

4. Results

4.1. CSFB larval populations

Larval populations varied considerably between counties and sites selected as being at high or low risk from the pest (Figure 1). The largest population was found at a high risk site in Cambridgeshire (mean of 45 larvae per plant) and the lowest at a low risk site in Lincolnshire (mean of 0.7 larvae per plant). Across sites larval numbers were significantly higher at high risk sites (mean of 14.2 larvae per plant) than low risk sites (mean of 5.9 larvae per plant) (df = 1, F = 12.72, P = 0.004). An interaction between county and risk was evident with significant differences in mean larvae per plant between high and low risk sites only in Cambridgeshire (df = 5, F = 3.18, P = 0.024). Averaging across high and low risk sites, larval numbers were significantly different between counties (df = 5, F = 5.59, P = 0.007), with the highest mean population in Cambridgeshire (mean of 20.7 larvae per plant) and the lowest in East Yorkshire (mean of 2.8 larvae per plant) (Figure 2).

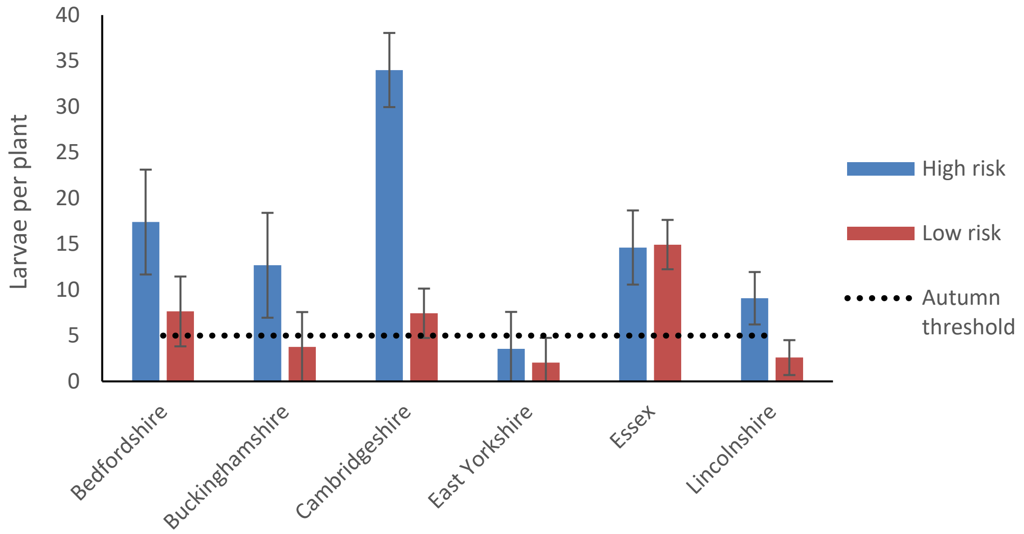

Figure 1. Mean larvae per plant in February/March at high and low risk sites in each county. Bars indicate standard errors of the means. Dashed line indicates the autumn treatment threshold.

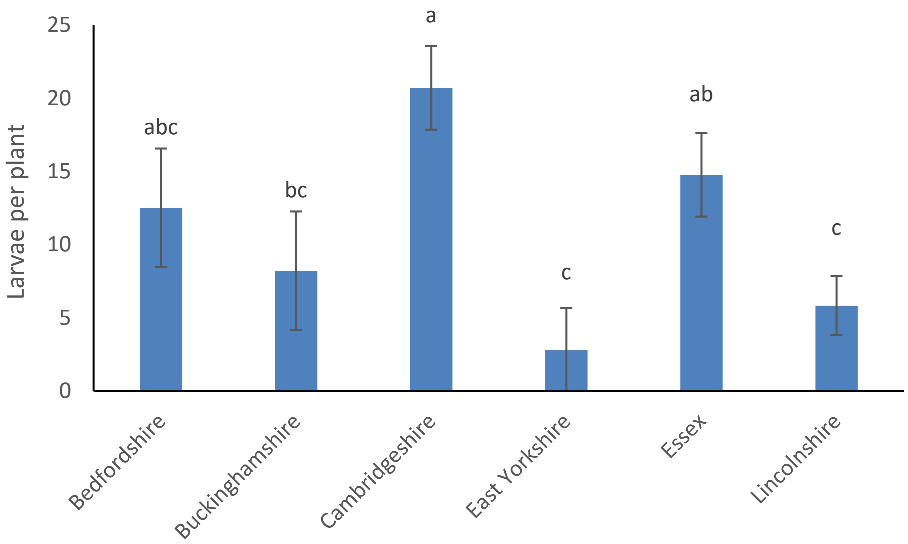

Figure 2. Mean larvae per plant in each county. Bars indicate standard errors of the means. Bars followed by the same letter are not significantly different. Significant differences are identified using LSD ($P<0.05$).

Across sites significantly more larvae were found in the petioles (mean of 9.7 larvae per plant) than the stem (mean of 0.4 larvae per plant) (df = 1, F = 71.57, $P < 0.001$). However, an interaction with risk was evident, with significantly more larvae in the petioles at high risk sites (mean of 13.7 larvae per petiole) than low risk sites (mean of 5.7 larvae per petiole) but no significant difference between the number of larvae in the stem at high risk sites (mean of 0.5 larvae per stem) and low risk sites (mean of 0.2 larvae per stem) (df = 1, F = 12.19, P = 0.002). The position of larvae in the plant was significantly affected by the interaction of county and risk (df = 5, F = 2.89, P = 0.035) with the number of larvae in the petioles but not the stems differing significantly between counties and high and low risk (Figures 3a and 3b).

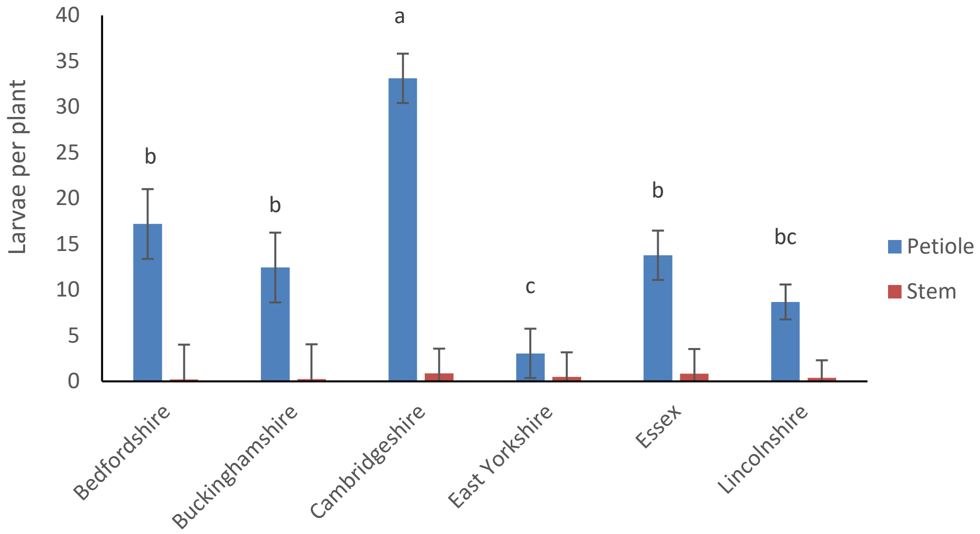

Figure 3a. Mean larvae per plant in the stem and petiole at high risk sites in each county. Bars indicate standard errors of the means. Bars for petiole data that are followed by the same letter are not significantly different. No significant differences were found between stem data. Significant differences are identified using LSD (P<0.05).

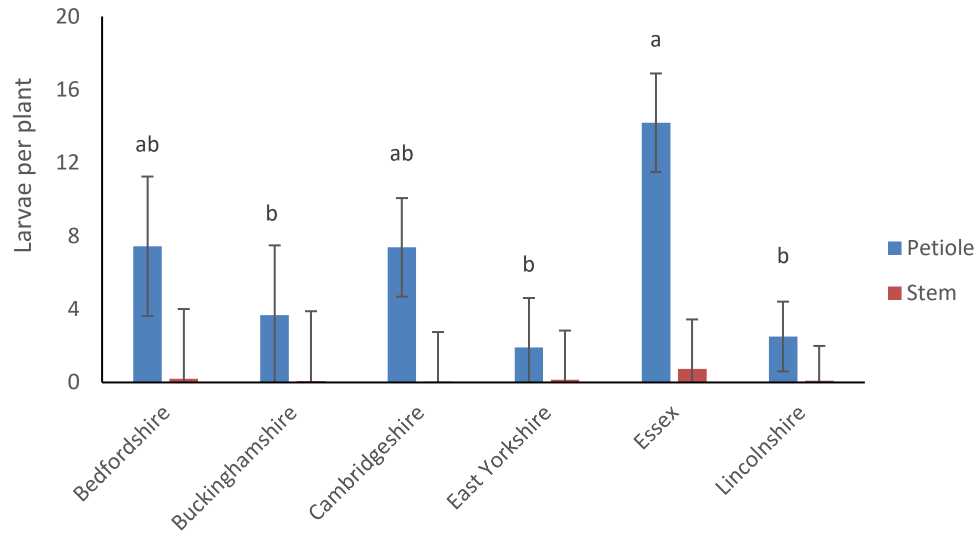

Figure 3b. Mean larvae per plant in the stem and petiole at low risk sites in each county. Bars indicate standard errors of the means. Bars for petiole data that are followed by the same letter are not significantly different. No significant differences were found between stem data. Significant differences are identified using LSD (P<0.05).

4.2. Risk factors for larval pressure

Regression analyses of larval populations against agronomic factors (Table 2) found significant relationships between the mean larvae per plant and percent leaf area lost at the cotyledon stage (Figure 4), percent leaf area lost at the 3-4 leaf stage (Figure 5) and the number of leaves per plant at the larval assessment date (Figure 6). These figures show that one site was an outlier in the data set (Cambridgeshire, high risk = mean of 45 larvae per plant).

Table 2. Regression analyses of mean larvae per plant and agronomic factor. % VAF = percent variance accounted for. * % VAF not calculated as residual variance exceeds variance of response variate. ** Defined as sprays providing >50% control. † Defined as sprays applied before 1 November. ‡ Defined as sprays applied between 1 November and 29 February.

Factor	P-value	F	F df	Residual df	% VAF
Adult CSFB damage at cotyledon stage (%)	<0.001	22.1	1	22	47.8
No. of leaves at assessment date	0.006	9.25	1	*22*	26.4
Adult CSFB damage at 3-4 leaf stage (%)	0.006	9.25	1	22	26.4
County	0.062	2.59	5	18	25.7
Drill date	0.127	2.28	2	21	10
Assessment date	0.371	1.19	9	19	7
No. of effective pyrethroid sprays **	0.296	1.33	3	18	4.5
No. of pyrethroid sprays to larval CSFB ‡	0.230	1.52	1	22	2.2
Variety	0.904	0.46	13	10	*
Seed rate (seeds per m²)	0.718	0.13	1	22	*
Establishment technique	0.935	0.14	3	20	*
Mesurol seed treatment	0.788	0.07	1	22	*
OSR (winter and spring) rotation frequency	0.827	0.3	3	20	*
Previous crop	0.671	0.64	5	18	*
Distance to nearest previous OSR (winter and spring)	0.529	0.41	1	22	*
No. of pyrethroid sprays to adult CSFB †	0.975	0.00	1	22	*
Total no. of pyrethroid sprays to CSFB	0.560	0.35	1	22	*

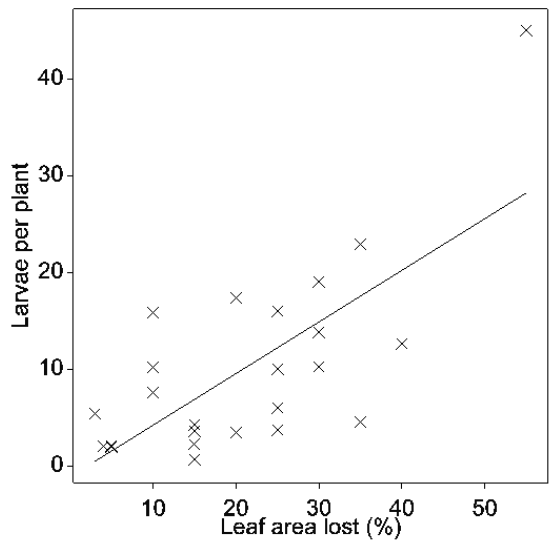

Figure 4. Relationship between mean larvae per plant and mean percent leaf area lost due to adult CSFB damage at the cotyledon stage. Line indicates fitted regression line. $R^2 = 0.501$, VAF = 47.8%.

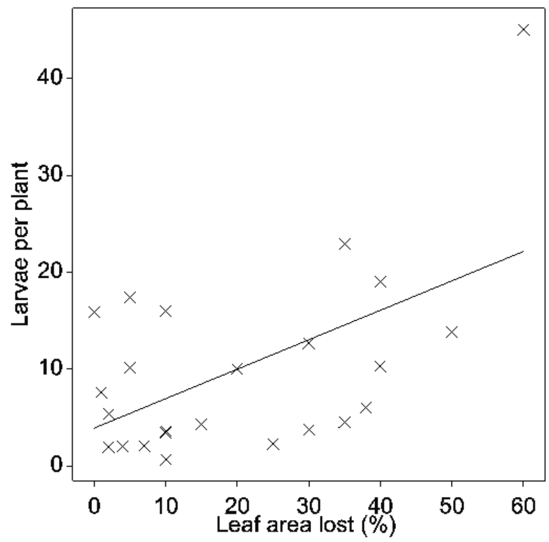

Figure 5. Relationship between mean larvae per plant and mean percent leaf area lost due to adult CSFB damage at the 3 to 4 leaf stage. Line indicates fitted regression line. $R^2 = 0.296$, VAF = 26.4%.

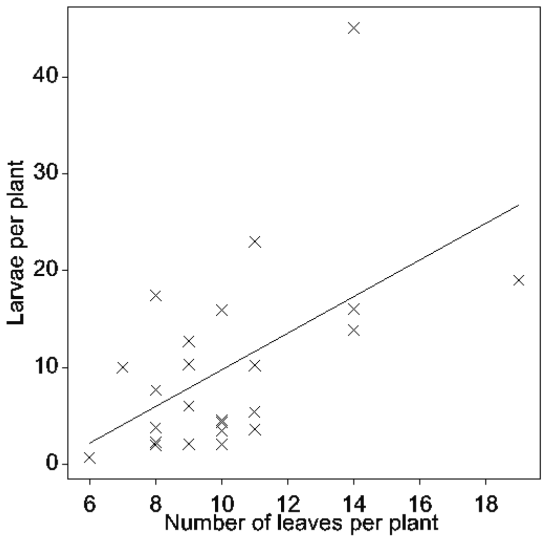

Figure 6. Relationship between mean larvae per plant and mean leaves per plant at the larval assessment date. Line indicates fitted regression line. $R^2 = 0.296$, VAF = 26.4%.

To determine whether the mean larvae per plant could be better predicted by a model consisting of two or more of these factors, those that were significantly associated with mean larvae per plant were included in a stepwise multiple regression analysis. This analysis identified the following final model, consisting of two factors and their interaction:

Mean larvae per plant in February/March = 19.3 - (0.761 x percent leaf area lost at the cotyledon stage) - (1.82 x number of leaves per plant in February/March) + (0.1117 x percent leaf area lost at the cotyledon stage x number of leaves per plant in February/March)

This model, with observed and predicted values shown in Figure 7, accounted for 64% of the variance in mean number of larvae per plant (df, = 2, F = 15.46, $P < 0.001$, $R^2 = 0.687$).

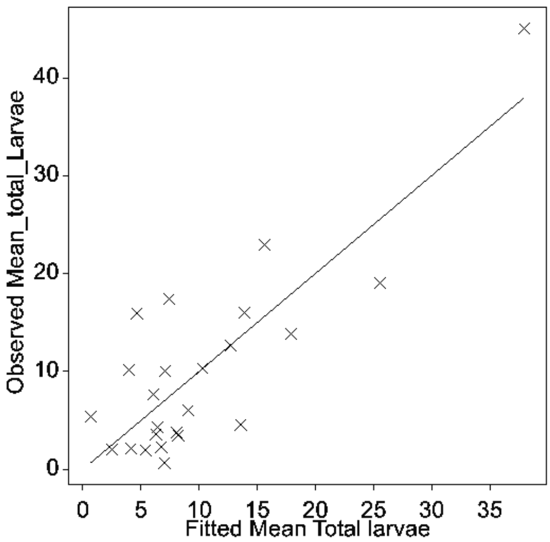

Figure 7. Comparison of observed mean larvae per plant with the values predicted in the model for predicting mean larvae per plant in February/March. Straight line = fitted equation for the relationship between the observed and predicted values. R^2 = 0.687, VAF = 64%.

4.3. Yield impacts

The yield of WOSR in the monitored fields was compared with the average yield for the same fields. The average yield is based on historical yield data, which ranged from one to four years for each site. Interpretation of yield data must be treated with some caution as only a single replicate site was studied for high and low risk crops in some counties and also because the yield could have been affected by other factors, e.g. weather conditions or disease.

The 2016 average yield across the sites was 3.3 t/ha (Table 3), which was 0.6 t/ha lower than the 2015 average for England and 0.3 t/ha lower than the five year (2011–15) average for England (Defra, 2016). At 20 out of 24 sites (83%) the 2016 WOSR yield was lower than the field average yield. As only a single value was available for each site for yield in 2016, statistical analysis of the differences between these and the historical yields was not possible. Averaging across all sites, the 2016 yield was 0.8 t/ha lower than the field average (Table 3) and the difference ranged between -2.5 t/ha and +0.9 t/ha. For low risk sites the average yield reduction was 0.7 t/ha (range -2.5 t/ha to +0.6 t/ha) and for high risks sites the average yield reduction was 0.8 t/ha (range -2.0 t/ha to +0.9 t/ha) (Table 3). For counties, the largest mean yield differences were in Essex (-1.6 t/ha) and Cambridgeshire (-1.5 t/ha), and the smallest mean yield difference was in Lincolnshire (mean yield difference = 0 t/ha) (Table 3). Full details of yield results can be seen in Appendix 2.

Table 3. Mean yield at harvest for 2016, historical yield for study fields and difference between 2016 yield and historical yields. Mean values shown for counties and risk sites.

County	High risk			Low risk			Mean 2016 yield for county (t/ha)	Mean historical yield for county (t/ha)	Mean yield difference for county (t/ha)
	Mean 2016 yield (t/ha)	Mean historical yield (t/ha)	Mean yield difference (t/ha)	Mean 2016 yield (t/ha)	Mean historical yield (t/ha)	Mean yield difference (t/ha)			
Bedfordshire	3.5	3.9	-0.4	3.0	3.8	-0.8	3.3	3.8	-0.6
Buckinghamshire	2.4	4.0	-1.5	3.8	4.4	-0.6	3.1	4.2	-1.1
Cambridgeshire	3.0	4.6	-1.6	3.4	4.6	-1.3	3.2	4.6	-1.5
East Yorkshire	3.2	4.0	-0.8	3.4	4.2	-0.8	3.3	4.1	-0.8
Essex	2.3	3.6	-1.4	1.3	3.1	-1.8	1.8	3.3	-1.6
Lincolnshire	4.0	4.1	-0.1	4.1	4.1	0.0	4.0	4.1	0.0
Total	3.2	4.0	-0.8	3.3	4.0	-0.7	3.3	4.0	-0.8

Regression analysis using data from the 2015 and 2016 CSFB larval surveys showed a significant relationship (df = 1, F = 10.89, P = 0.002, R^2 = 0.243) between mean number of larvae per plant and yield difference (using the field average yield), with a linear regression fitted to the combined data from both years accounting for 22% of the variance (Figure 8). It should be noted that yield responses will be also be due factors other than larval CSFB feeding.

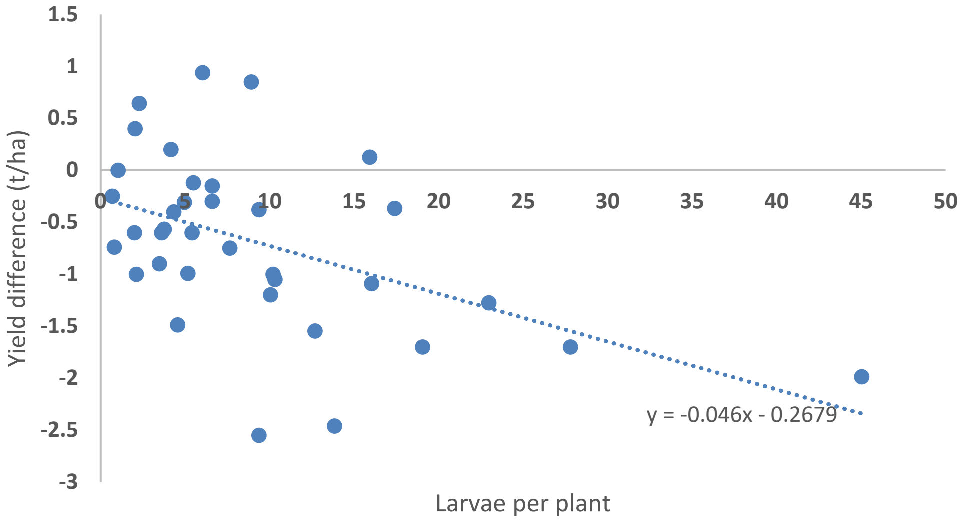

Figure 8. Mean number of larvae per plant (in February/March) plotted against the yield difference (yield minus field average yield). Data shown is for the 2015 and 2016 larval surveys. Dashed line indicates the best fit of the regression analysis. R^2 = 0.243, VAF = 22%.

4.4. Insecticide use and efficacy

Pyrethroids accounted for 85.2% of all foliar insecticides applied to the study fields, with neonicotinoids (11.5%) and pyridine azomethine derivatives (3.3%) accounting for the remaining applications. CSFB was listed as the reason given for 82% of foliar insecticide applications (Figure 9). Geographical differences in pest incidence were evident, with treatments for seed weevil only applied in East Yorkshire, autumn aphids in Essex and Buckinghamshire, and pollen beetle in Cambridgeshire and Essex.

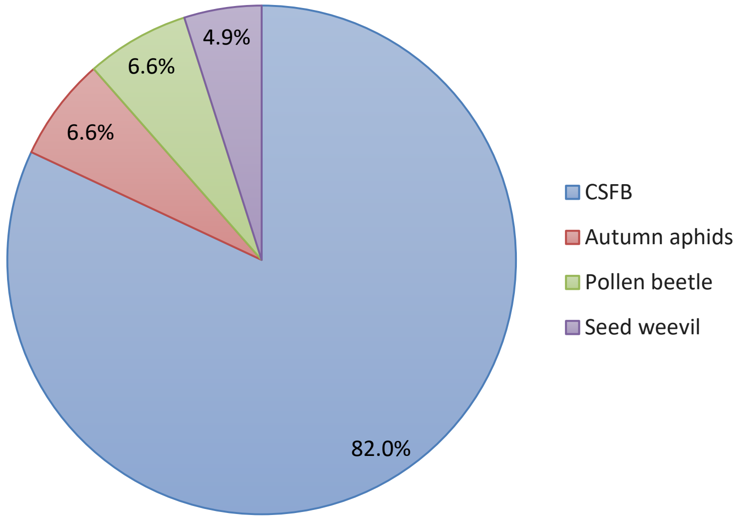

Figure 9. Target pest for foliar insecticide applications as percentage of total foliar insecticides applied in the 2016 cropping year.

Pyrethroids accounted for 98% of all foliar insecticides applied for CSFB control, with neonicotinoids (2%) accounting for the remaining applications. Insecticides were applied for CSFB control at all but two sites (92% of sites). The mean number of pyrethroid applications for CSFB control ranged from 1.5 at sites in Cambridgeshire and Essex to four at the high risk site in Buckinghamshire (Figure 10).

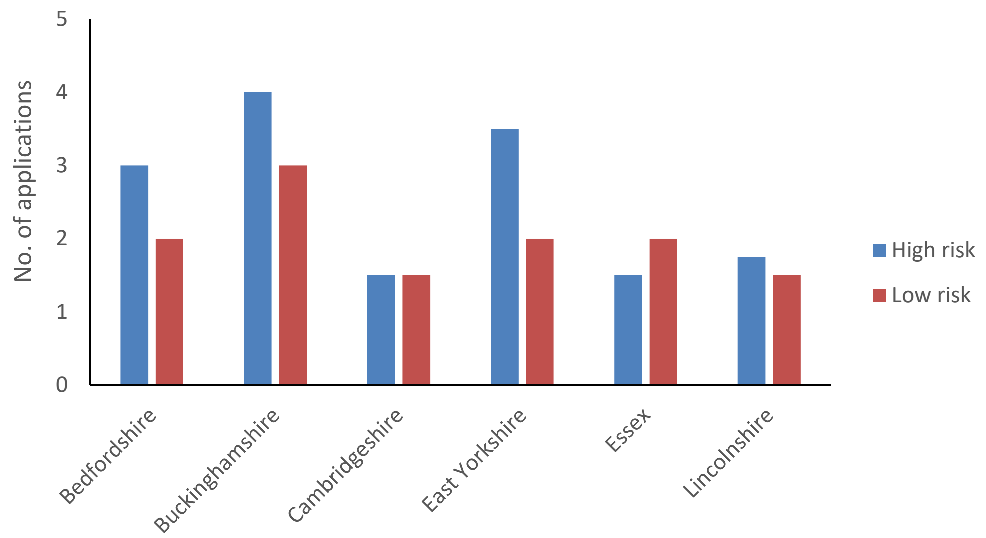

Figure 10. Mean number of pyrethroid sprays applied for CSFB control at high and low risk sites in each county.

Of the 50 insecticides applied for CSFB control, 76% (38 applications) targeted adults and 24% (12 applications) targeted larvae. Of the applications applied for control of adults, 49% (18 applications) occurred at 13 sites where adult feeding damage was below the adult feeding thresholds of less than 25% of leaf area lost at the cotyledon stage and 50% of leaf area lost at the three to four leaf stage. Agronomists estimated that 38% of treatments for CSFB (19 applications) resulted in more than 50% control. The effectiveness of pyrethroid sprays for CSFB control also appeared to vary with location; in Lincolnshire and East Yorkshire 85% and 55% of treatments respectively were deemed to provide more than 50% control compared to 0% of treatments in Bedfordshire and Essex (Figure 11).

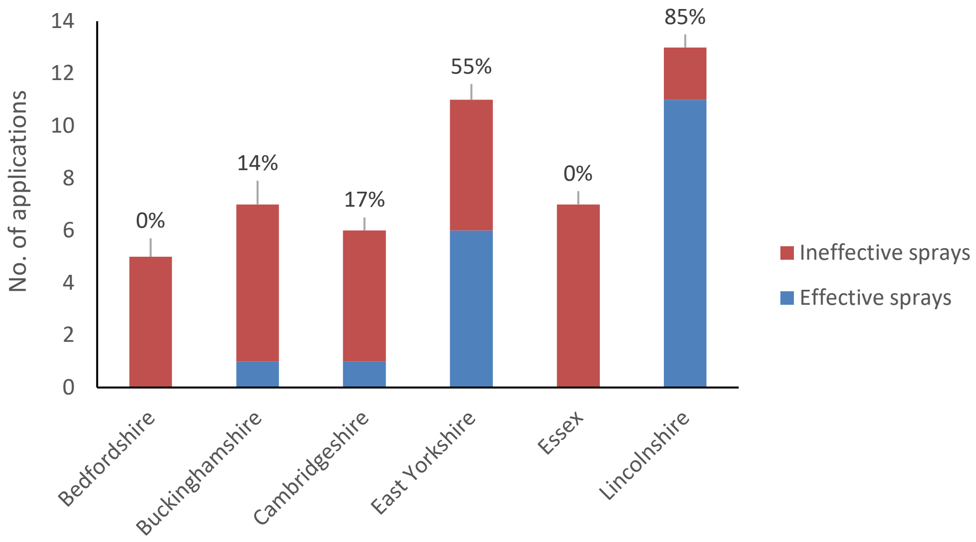

Figure 11. Total effective (resulting in more than 50% control) and ineffective pyrethroid applications at the sites monitored in each county in the 2016 cropping year (as reported by agronomists). Value above each bar shows the percentage of effective sprays.

5. Discussion

There were significant differences in the CSFB larval populations between the counties at the sites monitored in spring 2016, with the largest numbers found in Cambridgeshire and the smallest numbers found in East Yorkshire and Lincolnshire. In comparison with results from the 2015 survey (White, 2015), populations in 2016 rose in Cambridgeshire at high risk sites by 22.3% (2015 = 27.8 larvae per plant, 2016 = 34 larvae per plant) and low risk sites by 12.1% (2015 = 6.6 larvae per plant, 2016 = 7.4 larvae per plant) and in Bedfordshire at high risk sites by 138.4% (2015 = 7.3 larvae per plant, 2016 = 17.4 larvae per plant) and low risk sites by 111.1% (2015 = 3.6 larvae per plant, 2016 = 7.6 larvae per plant). Other counties were not assessed in both years. These increases in larval populations between the 2015 and 2016 surveys may be partly due to differences in winter temperatures. The mean temperature for the regions in which larval populations were surveyed in winter 2014/15 was 2°C compared to 6°C for the regions surveyed in winter 2015/16 (Met Office, 2016). As CSFB oviposition is limited by temperatures below 4°C (Højland *et al.*, 2015; Mathiasen *et. al,* 2015) and egg development by temperatures below 3.2-5.1°C (Alford, 1979; Mathiasen *et. al,* 2015), the warmer conditions in winter 2015/16 will have permitted greater levels of egg-laying and egg-hatch, resulting in larger larval populations the following spring. This is supported by data from the Fera Crop Monitor surveys, which show that between autumn 2014 and spring 2015 the mean number of larvae per plant in the south-east, east and north increased by 14% (from a mean of 1.3 per plant in the autumn to a mean of 1.4 per plant in the spring) compared to an increase of 243% in the same regions in winter 2015/16 (from 2.1 larvae per plant in autumn to 4.5 larvae per plant in spring) (Crop Monitor, 2016).

In terms of the location of the larvae in the plant, 96% were found in the petioles in 2016, a figure very similar to that observed in the February 2015 survey (95%) (White, 2015). The proportion of larvae in the petioles also remained consistent between high and low sites despite there being significantly higher numbers in the petioles at high risk sites compared to low risk sites. For example, at the high risk sites in Cambridgeshire the mean number of larvae in the petioles and stems was 34 and 0.9 respectively. This suggests that high numbers of larvae in the petioles do not trigger movement to the stem, or at least had not done so by the dates that the sites were sampled (February/March). Larvae are thought to migrate from the petioles to the stems mainly in March and April, which is supported by data from the April 2015 survey (White, 2015) when the proportion of larvae in the petioles were found to have dropped from 95% in February to 65% in April.

The position of the larvae in the plant is important as, although there is little evidence in the literature, logic would suggest that feeding in the stem would have a greater impact on yield than feeding in the petioles simply because the flow of nutrients to the developing pods would be reduced. However, the cues that the larvae use to time migration from the petioles to the stem are little understood. Other cues that the larvae could use to trigger this behaviour include chemical changes in the host plant (e.g. plant hormones that mediate stem elongation) and seasonal changes in environmental conditions such as increases in temperature and day length. If more was known about such cues then this could be used to better predict the impact of larvae on yield and potentially to time insecticides applications to better target the exposed larvae as they move between the petiole and stem.

In terms of risk, agronomists were typically able to predict sites at which CSFB larval pressure would be high or low. However, the criteria used to determine risk differed between agronomists, e.g. adult feeding damage, frequency of winter or spring OSR in the crop rotation and CSFB pressure in previous crops. Larval numbers in autumn can be predicted by monitoring the numbers of adults caught in yellow water traps (Green, 2008) but it is unlikely that many farmers or agronomists use this method. Therefore, determining other reliable, easy to use indicators of larval pressure would be useful. This work identified three factors that were significantly related to larval populations in spring; adult feeding damage at the cotyledon and three to four leaf stage, and the number of leaves in the spring. That other factors were not found to be significantly associated with the size of larval populations does not necessarily mean they have no effect, just that the sample size was too small to properly test the relationship. A statistical model identified that together, adult feeding damage at the cotyledon stage, the number of leaves in February/March, and the interaction of these two factors, provided the best prediction of larval number, accounting for 64% of the variance in mean number of larvae per plant. It should be noted that this relationship is based on data gathered from relatively few sites in a single year and that a larger data set would allow all factors to be properly assessed and improve the reliability any relationships identified. It is recognised that number of leaves in February/March may be too late to apply treatments for the control of larvae but adult damage at the cotyledon stage accounted for 47.8% of variance in larval number and would be a timelier indicator for predicting likely larval damage.

The growers in this study relied almost solely on the use of pyrethroid foliar insecticides for the control of CSFB adults and larvae (98% of foliar CSFB treatments). This is similar to the pattern of CSFB control methods found in the 2015 survey, when 100% of all treatments for CSFB were pyrethroids (White, 2015). As in 2015, none of the growers used neonicotinoid seed treatments due to the continued restrictions on their use. However, while growers in Bedfordshire and Cambridgeshire were able to drill some WOSR treated with neonicotinoids in autumn 2015 (as part of the derogation allowing limited use of these seed treatments in specific counties), such crops were not monitored in this work to ensure a consistent methodology with the 2015 larval survey (White, 2015). The majority of sprays for CSFB targeted the adults (76%) rather than the larvae (24%). Of the insecticides applied for adult CSFB control, nearly half occurred despite feeding damage being below the treatment threshold at both the cotyledon and three to four leaf stage. Some sprays may have been justified on the basis that crops were growing more slowly than they were being eaten (a further treatment threshold). Also some sprays may have been targeting early hatching larvae (adult sprays were defined as though applied before 1 November). Nevertheless, some applications may have been unnecessary and potentially selected for resistance. That fewer treatments targeted the larvae may be due to the difficulty in determining whether the larval threshold has been reached, the potential reduced effectiveness of sprays against a stage that is protected by being inside the plant most of the time, and the difficulty in timing sprays to optimise efficacy (e.g. by coinciding with movement of the larvae into and out of the plant).

As in the 2015 larval survey (White, 2015), the majority of sprays for CSFB (62% in 2015 and 62% in 2016) were not considered by agronomists to provide more than 50% control. However, the effectiveness of control appeared to be affected by location, with 55% and 85% of spays considered to provide more than 50% control in East Yorkshire and Lincolnshire respectively compared to less than 18% of sprays in any of the other counties monitored, all of which were in the east or south-east of England. This is possibly due to regional differences in levels of pyrethroid resistance in

CSFB, which are highest in south-eastern and eastern England and lower in the north-east and Lincolnshire (AHDB, 2015, S. Foster, pers. comm.). Treating populations of CSFB containing pyrethroid resistant individuals with pyrethroids will increase the frequency of resistance in subsequent populations and may not provide effective control. It may also indirectly reduce pest control by killing beneficial natural enemies. Carabid beetles have been shown to be spatially associated with CSFB larvae and to predate CSFB eggs (Warner *et al.*, 2003) and pyrethroid sprays are known to be toxic to carabids (Wiles & Jepson, 1992). Therefore, if pyrethroids are applied in areas where there are resistant beetles they will not only be ineffective but also reduce carabid populations and may result in higher larval populations due to lower levels of egg predation.

This work showed that the CSFB was the main target for foliar insecticides in the crops monitored, accounting for 82% of all foliar insecticide applications. Other targets for insecticides were pollen beetle (7%), autumn aphid (likely to be peach-potato aphid, 7%) and cabbage seed weevil (7%). These results differ markedly from those in the 2014 Pesticide Usage Survey in arable crops, which reported that 27%, 25% and 19% of insecticide applications were for CSFB, aphid (although this did not discriminate between aphids so some of these sprays may have been targeted against mealy cabbage aphid control in the spring) and pollen beetle control respectively (Garthwaite *et al.*, 2015). It should be noted that the Pesticide Usage Surveys cover pesticide applications in all counties and so are not a direct comparison to the usage detailed in this report. Nevertheless, the increase in the proportion of sprays for CSFB control recorded in this work probably reflects the increased CSFB pressure that has been experienced in the last two years, reductions in control efficacy due to resistance and the lack of alternative control options. The reduction in the proportion of sprays for pollen beetle control in this work may reflect a longer term trend, with the pest accounting for 23% of sprays in the 2012 Pesticide Usage Survey (Garthwaite *et al.*, 2013), higher than the percentage in both this project (7%) and the 2014 Pesticide Usage Survey (19%). It is possible that this trend is due to the revised treatment thresholds for pollen beetle (Ellis & Berry, 2012) and the realisation that these pests are less damaging than previously thought. A consequence of applying fewer insecticides for pollen beetle control in the spring is that it is likely to benefit *Tersilochus microgaster*, a parasitic wasp that is an important endoparasitoid of CSFB larvae (Ulber *et al.*, 2015a), which is active during the period when pollen beetle treatments are applied (Ulber *et al.*, 2015b). Overall, pyrethroids accounted for 85% of all foliar insecticides applied to the study crops which, while lower than that reported in the 2014 Pesticide Usage Survey when 93% of all insecticides applied to arable crops were pyrethroids (Garthwaite *et al.*, 2015), represents a very strong selection pressure for pyrethroid resistance, exacerbating current problems and making new cases of resistance more likely.

Yield reductions compared to the average for the field were reported at 83% of sites and while a number of factors will have affected these yield differences, the high larval populations at a number of sites are likely to be at least partly responsible. The mean number of larvae per plant was above the autumn treatment threshold (five larvae per plant) at 50% of sites monitored, all of which reported yield reductions ranging from -0.4 to -2.5 t/ha. However, as these sites were monitored in February/March it is difficult to relate them to population sizes in the autumn. It would be expected that larval numbers would increase in the period between autumn and February/March but the degree of change can vary. Fera's Crop Monitor showed that during winter 2014/15 larval numbers increased 14% between autumn and spring compared to 243% in winter 2015/16 (Crop Monitor, 2016). This difference is likely due to the higher temperatures in winter 2015/16 than in 2014/15. The current larval threshold is based on a yield response of 0.34 t/ha to five larvae per plant in late October/early November (Purvis, 1986) but the additional impact of late hatching larvae will largely depend on the size of the larvae at the point at which the plant is most affected by larval feeding. For instance, larvae that hatch in spring are likely to be considerably smaller and feed less than those that hatch in autumn when stem elongation begins, minimising their impact on yield.

This work found a significant negative correlation between the number of larvae per plant in February/March and yield at harvest. This predicted infestation of five, ten and twenty larvae per plant in February/March would result in yield reductions of -0.5, -0.7 and -1.2 t/ha. However, the yield response to larvae did not fit this trend at all sites. These discrepancies may be explained by the qualitative descriptions of other factors that may have affected the yield at each site that were provided by the agronomists. At a number of sites, the yield impact was higher than would be expected based on the number of larvae found in the plants. For instance, a very high yield reduction was reported (-2.5 t/ha compared to the field average) at a site that had a mean of 13.8 larvae per plant, however, the agronomist reported that 50% of leaf area had been lost to adult CSFB at the 3-4 leaf stage and that very high aphid pressure had been experienced in the autumn. These factors could have contributed to the yield reduction, especially if the aphid infestation resulted in early turnip yellows virus infections that affected much of the crop. A further site that had a mean of 12.7 larvae per plant also had a higher than expected yield reduction (-1.6 t/ha compared to the field average) but here the agronomist reported that heavy soil resulted in variable emergence, which was compounded by high slug and adult CSFB activity. Weather conditions are also likely to have had a major impact on yield in 2016. For instance, a site in East Yorkshire that had low larval numbers (mean of 2.1 larvae per plant) but a relatively high yield reduction (-1 t/ha compared to the field average) had little rain after drilling, resulting in poor rooting. In addition, a late, wet spring limited photosynthesis at seed fill. Equally, there were a number of sites at which yield was higher than expected based on the larval populations. For instance, a site that had a mean of 17.4 larvae per plant showed a yield reduction of just -0.4 t/ha, while sites that had a mean of 15.9 and 6 larvae per plant showed yield increases of 0.1 and 0.9 t/ha respectively. These variations illustrate the difficulty in accurately predicting yield response due to larval feeding. It should also be noted that these yield differences are based on limited data (single data points per field per year), which limits their statistical reliability.

An AHDB-funded project (Project No. 211200) investigating an integrated pest management approach for CSFB started in August 2016 and will help to meet some research requirements identified in this report. The use of adult feeding damage and leaf number to predict larval pressure described in this work suffers from a relatively small data set but the new project will use a much larger data set (comprising data from several previous research projects and data collected as part of the new project) to identify the risk factors that contribute to adult and larval pressures. The large data set will improve the reliability of any risk assessment developed. The susceptibility of a range of commercially available WOSR varieties to larval feeding will be also be assessed, which may help growers select varieties with increased tolerance in areas at high risk of significant CSFB pressure. A series of replicated field trials will also provide a better understanding of the impact of larvae on yield and allow the current treatment threshold to be reviewed. Finally, novel control methods will be investigated that potentially allow growers to reduce the yield impact of high larval populations.

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7. Appendices

7.1. Appendix 1. Agronomist questionnaire

Cabbage Stem Flea Beetle (CSFB) larval survey 2015/16 questionnaire						
Section 1 - Site details						
1	County being assessed:					
2	Risk category (high or Low):					
3	Farmer/business name and address:					
4	Telephone:					
5	Email:					
6	Date sampled:					
7	Field coordinates/grid ref.:					
8	Field name or number:					
9	OSR variety:					
10	Cultivations and seed bed preparation:					
11	Drilling date:					
12	Drilling method:					
13	Seed rate:					
14	Was a mesurol seed treatment used?					
15	Past cropping:					
	2014/15:					
	2013/14:					
	2012/13:					
	2011/12:					
16	Is the current OSR crop adjacent to or further away from the previous OSR crop?					
Section 2 - Pesticide usage: Please provide the following information on pesticides used from drilling to harvest. This includes insecticides, herbicides and fungicides.						
17	Date	Product	Rat e	Target (if CSFB then please state whether this was for adults or larvae)	Estimated level of control (%)	Pest, disease or weed pressure (low, medium or high)

	Section 3 - CSFB pressures:	
	Adults:	
18	What was the overall adult CSFB pressure (Low, medium or high)?	
19	If known, when did CSFB adults migrate into the crop?	
20	What was the average foliar damage (%) from CSFB at the cotyledon to second true leaf stage?	
21	What was the average foliar damage (%) from CSFB at the 3-4 leaf stage?	
22	Were adults monitored using yellow water traps?	
22 a	If so, was trapping done as per the AHDB Cereals and Oilseeds Information Sheet 43, i.e. four traps placed in early September, emptied and refilled each week, with the number of cabbage stem flea beetle recorded and added to the previous total? Please give the total number of beetles caught over the whole monitoring period divided by the number of traps to calculate an average number of beetles per trap over the trapping period?	
22 b	If adults were monitored over other durations please describe this here and detail how many adults were caught on average over this period.	
	Larvae:	
23	Were plants monitored for leaf-scarring? If so, what percentage of petioles had leaf-scarring?	
24	Were plants dissected and assessed for larval numbers in the autumn? If so, what was the average number of larvae per plant?	
	Section 4 - Yield in field sampled	
25	Yield at harvest (t/ha):	
26	Average yield (t/ha) from last five OSR crops (in field sampled):	

Section 5 - Please use this space to make any comments that you feel may have affected CSFB pressures at this site (both adult and larval) and yield. Feel free to use another page if necessary:	
27	

7.2. Appendix 2. Mean larval populations in February/March and yield data at each site.

County	Risk	Mean larvae per plant in petioles	Mean larvae per plant in stems	Mean total larvae per plant	2016 yield (t/ha)	Average field yield	Yield difference (t/ha)
Bedfordshire	Low	7.4	0.2	7.6	3.0	3.8	-0.8
Bedfordshire	High	17.2	0.2	17.4	3.5	3.9	-0.4
Buckinghamshire	High	3.7	0.1	3.8	3.8	4.4	-0.6
Buckinghamshire	Low	12.4	0.2	12.7	2.4	4.0	-1.5
Cambridgeshire	High	10.2	0.1	10.3	3.5	4.5	-1.1
Cambridgeshire	Low	4.6	0.0	4.6	3.3	4.7	-1.5
Cambridgeshire	High	43.6	1.4	45.0	2.5	4.5	-2.0
Cambridgeshire	Low	22.6	0.4	23.0	3.5	4.8	-1.3
East Yorkshire	Low	2.1	0.0	2.1	3.0	4.0	-1.0
East Yorkshire	High	1.8	0.2	2.0	3.7	4.3	-0.6
East Yorkshire	High	3.4	0.2	3.6	3.3	3.9	-0.6
East Yorkshire	Low	2.7	0.8	3.5	3.1	4.0	-0.9
Essex	Low	13.4	0.4	13.8	0.5	3.0	-2.5
Essex	High	15.0	1.1	16.0	2.1	3.2	-1.1
Essex	Low	10.0	0.2	10.2	2.5	3.5	-1.0
Essex	High	17.5	1.5	19.0	2.0	3.7	-1.7
Lincolnshire	High	2.1	0.2	2.3	4.7	4.0	0.6
Lincolnshire	Low	2.0	0.1	2.0	5.0	4.6	0.4
Lincolnshire	High	5.4	0.0	5.4	3.2	3.8	-0.6
Lincolnshire	Low	0.6	0.1	0.7	3.7	4.0	-0.3
Lincolnshire	High	5.8	0.2	6.0	4.8	3.9	0.9
Lincolnshire	Low	4.2	0.1	4.3	3.9	4.3	-0.4
Lincolnshire	Low	14.8	1.2	15.9	4.0	3.9	0.1
Lincolnshire	High	10.0	0.1	10.0	3.1	4.3	-1.2