The impact of the EU neonicotinoid seed-dressing ban on oilseed rape production in England

Running title: Impact of neonicotinoid seed-dressing ban on oilseed rape production in England

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Abstract

BACKGROUND:

Neonicotinoid seed dressings were banned on oilseed rape in the EU from December 2013. A survey was conducted of >200 farms in England in the 2014/15 and 2015/16 seasons to assess the impact the ban was having on changes in crop area, crop losses to cabbage stem flea beetle (CSFB), insecticide use and the economics of oilseed rape production.

RESULTS:

The area of oilseed rape grown fell in both seasons with CSFB identified as the third most important reason. Crop losses to CSFB were 3% and 5% in the respective seasons with clear variation by county. There were clear differences in the crop area treated (1.14 vs 0.77 million hectares) and number of applications per crop (2.0 vs 1.4) of insecticide to combat CSFB in 2014/15 and 2015/16 respectively. Within the Derogation Area (DA) counties there was a clear reduction in the number of applications per crop when neonicotinoid treated versus non treated seed was used (1.0 vs 1.9) respectively.

CONCLUSION:

Increasing resistance to pyrethroid insecticides in combination with the neonicotinoid seed dressing ban is likely to have significant impacts on the viability of growing oilseed rape in England particularly where CSFB activity/risk is high.

Keywords: oilseed rape (*Brassica napus* L.), cabbage stem flea beetle (*Psylliodes chrysocephala*), insecticide, neonicotinoids, financial cost.

1 INTRODUCTION

Neonicotinoids are a group of systemic insecticides first registered for use in 1994 that by 2008 represented 24% of the global insecticide market and 80% of the seed treatment market.[1] In 2014 just over 725,000 hectares of oilseed rape (*Brassica napus* L.) in the UK had a seed treatment with 3 of the top 5 applications being neonicotinoids i.e. thiamethoxam (Cruiser), clothianidin (Modesto) and imidacloprid (Chinook) respectively accounting for 87% of the treated area.[2] Imidacloprid was the first neonicotinoid seed dressing approved for use in the UK on sugar beet [3] and was the first new broad spectrum systemic neonicotinoid insecticide approved for use on oilseed rape crops in 2000, with clothianidin and thiamethoxam subsequently approved for use (2006 and 2010 respectively) which have since overtaken imidacloprid in terms of use. [4]

Neonicotinoids can be applied to a crop as a seed treatment or a foliar spray. Seed dressings are an effective means of pest and pathogen control as they deliver high efficacy of control at a reduced rate when compared with many foliar or soil applied alternatives.[5] Neonicotinoid seed dressings are used on oilseed rape in the UK particularly to protect the crop against cabbage stem flea beetle (*Psylliodes chrysocephala*) other flea beetles and peach-potato aphids that transmit turnip yellow virus (TuYV).[6] Cabbage stem flea beetle (CSFB) is the most widely distributed stem mining pest of oilseed rape crops in Europe which can significantly reduce crop establishment and yield.[7]

The European Commission from December 2013 suspended the use of neonicotinoid seed dressings (Regulation No 485/201) including imidacloprid (Chinook), clothianidin (Modesto) and thiamethoxam (Cruiser) on bee attractive crops (such as oilseed rape) because of a perceived hazard to bees. [8] This has resulted in the potential for increased damage to oilseed rape crops during early establishment and in a potential loss of confidence in the crop by

some growers. In the absence of neonicotinoid seed treatments, control of CSFB is reliant on the use of foliar pyrethroid sprays and/or cultural control methods. Neonicotinoid foliar sprays have not been subjected to the EU ban as they are deemed to be safer to bees. [9, 10] In 2015 a derogation was granted by the UK government for 5% of the oilseed rape area (30,000 ha) to be treated with a neonicotinoid seed dressing in response to an epidemic of CSFB that caused serious damage in the autumn of 2014.[11] The four counties in England where this derogation was applied (Derogation Area) were Bedfordshire, Hertfordshire, Cambridgeshire and Suffolk.

There has been increasing debate over recent years concerning the role of insecticides and in particular neonicotinoids on the health of bees. Wild bees have undergone decline in the UK that has been linked to habitat loss, climate change and the use of pesticides in particular neonicotinoid seed dressings.[4, 12, 13] but with a limited evidence base to guide policymakers on how pollinator populations will be affected by neonicotinoid use. Exposure to neonicotinoid seed treatments has been negatively correlated with the population persistence of wild bee communities foraging on oilseed rape.[14] This was further supported by an investigation across three countries (Hungary, Germany, UK) of the impact of neonicotinoid treated oilseed rape on the reproductive potential of managed and wild bee species.[15] The study showed distinctly different patterns among the three countries with a reduced capacity of bee species to establish new populations in the year following neonicotinoid seed dressing exposure in Hungary and the UK but in Germany the only statistically significant effects on bee population factors of neonicotinoid exposure were positive (i.e. beneficial). A laboratory study showed exposure to clothianidin and thiamethoxam caused bumblebees to have diminished reproductive success,[16] with reduced colony numbers also shown.[17] Similar studies in the laboratory have shown reduced foraging ability of honey bees on exposure to imidaclopirid. [18, 19, 20] Large-scale pesticide usage observations from oilseed rape production across England and Wales showed

a correlation of imidaclopirid usage patterns with those detailing honey bee colony losses over an 11 year period.[21]

In contrast to the adverse effects of neonicotinoids on bee health there are a number of studies which show either no or a limited risk. No differences in bee mortality, worker longevity, or brood development occurred in a study following exposure of honeybees to clothianadin treated oilseed rape in Canada. [22] Pilling et al [23] also concluded that there was a low risk to honey bees from systemic residues in nectar and pollen following the use of thiamethoxam (at rates recommended for insect control) as a seed treatment on oilseed rape for four consecutive years in France. Blacquiere et al [9] reviewed 15 years of research on the hazards of neonicotinoids to bees and showed that while many laboratory studies described lethal and sub-lethal effects of neonicotinoids on foraging behavior and learning and memory abilities no effects were observed in field studies at field-realistic dosages. Quantitative weight of evidence analyses studies have also showed minimal risk to honeybees in the use of imidacloprid, clothianidin and thiamethoxam as seed treatments. [24, 25, 26]

The aim of this study was to assess the impact of the neonicotinoid seed dressing ban on oilseed rape production in England over a two year period using a stratified sample of oilseed rape growers. The survey elicited information on changes in production area, damage caused by CSFB and management practices used to alleviate pest damage.

2 MATERIALS AND METHODS

2.1 Farm survey

The Farm Business Survey (FBS), conducted annually, provides information on the physical and economic performance of farm businesses in England. There are 6 FBS regional offices with staff employed to collect and analyse farm performance data annually across the

agricultural sector. Surveys of sample farms were conducted for two crop production cycles 2014/15 and 2015/16. Sample farms were selected from the FBS on the basis of having grown WOSR (both high erucic and double low varieties) in the previous season and to give a geographic spread reflecting the total FBS response. The sample size was 205 and 203 farms for the 2014/15 and 2015/16 seasons respectively, which equated to nearly half the total number of FBS farms growing WOSR in each year. Farms were selected in proportion to the number of growers by region, and where possible, by county. Growers were asked 12 questions regarding: the areas grown for the current harvest (in relation to the previous crop area grown), the reasons for increasing or decreasing the area grown and strategies and chemicals used to combat actual, or expected, CSFB attacks. For both seasons farmers were surveyed by structured interview (telephone or face-to-face) by experienced FBS staff with the exception of 2015/16 when 25 growers were surveyed using a postal questionnaire. Farms surveyed had been in the FBS for an average of 8 years (in both 2015 and 2016) and ranged from new recruits to farms that have been included for 20 years.

2.2 Response variables

Winter oilseed rape planting area, insecticide treated area and potential loss of crop area for both 2014/15 and 2015/16 were examined with responses to 12 questions (Table S1) which were split into 3 sections. The first section related to: 'What area of WOSR did you plant', 'Is your planted area more or less than the previous season?' 'If so why?' and 'by how much?'

The second section related to insecticide use. 'Did you use insecticides to combat actual or predicted CSFB attacks? Or change agronomic practices to avert possible CSFB damage?' 'What chemical or chemicals and at what rate where they applied?' and 'What area was treated?' In addition to which growers were asked if they had used the services of an agronomist

in their choice of chemical to control CSFB as this can influence the management decisions taken and the farming outcomes.

The third section related to identifying the area of crop lost in particular; 'Was any crop area lost to CSFB? If so what area? Was damage so severe that you had to re-drill? and if so what area?'

For the 2016 survey because of the potential use of neonicotinoid treated seed in Derogation Area counties the following questions were also asked: 'Did you request treated seed? If so how much? and how much did you get?'

2.3 Control variables

Sample distribution was analysed at a county level (Fig 1) with adjacent counties grouped together to give a minimum sub-sample size of at least 10 farms in each year (Table 1). A comparison of the 2013 areas of WOSR grown by sample farms and the 2013 DEFRA (Department for Environment, Food and Rural Affairs) June Survey data [27] suggests that the sample represents 1.5% of growers and 1.8% of WOSR area grown in 2014/15 and 1.5% of growers and 1.6% of area grown in 2015/16.[28]

The sample data were weighted up to national level using weights calculated from the 2013 June survey population data for 2014/15 and from the 2015 June survey population data for 2015/16.[27, 28] The weights used were stratified according to the area of oilseed rape grown i.e. 0-5, 5-10, 10-20, 20-50, 50-100 and >100ha. These weights, when applied to the sample data, estimated the WOSR area grown in 2013 to be within 3% of the 2013 Defra June survey area and within 1.0% of the 2015 June survey area.

The use of insecticide is presented as area treated with prices obtained from local suppliers at the time of OSR establishment (so may be subject to some variation both across the country

and with scale of use). The cost of insecticide application and the costs of re-drilling (cost of seed and a "farmer's average cost" of drilling) are taken from Nix, [29, 30] with the assumption that all redrilled crops were with oilseed rape. Crop losses, for the area lost and not re-drilled, are calculated on the basis of the area lost and estimated Gross Margins per hectare for both seasons 2014/15 and 2015/16. [29, 30] Costs of implementing other changes in agronomic practice used by farmers have not been included in the analysis.

3 RESULTS

Twenty farms selected, which grew WOSR in 2012/13 and 2013/14 grew none in 2014/15. Likewise of the 203 farms surveyed in 2015/16, 25 did not grow oilseed rape in that year. The total area of WOSR grown on sample farms was 9,744 and 8,375 hectares in the 2014/15 and 2015/16 seasons respectively which represented 1.59 and 1.55 % of the winter oilseed rape area in England in the respective seasons.

3.1 Changes in crop area

In 2014/15, there was an overall decrease of 879.6 ha in the area of oilseed rape grown on sample farms compared to the previous season. This consisted of 66 farms growing less WOSR (1380 ha) than the previous season while 28 farms actually grew more (501 ha). There were clear differences between years and areas in the reduction in crop areas (Table 2). The greatest reduction recorded was 25.4% in Suffolk in 2015/16 whereas in the previous season the area was increased by 9.8%. The four merged DA counties had combined reduced crop areas of 20.0% and 12.4 % in 2014/15 and 2015/16 respectively. For 2015/16 the area of WOSR grown

was 1016 ha lower than in the previous season and consisted of 104 farms who grew less (1803 ha) while 75 farms grew more (787 ha). The most common reason given for the change in area grown in both seasons was "crop rotation", followed by "commodity price", and then "cabbage stem flea beetle". Even in the high risk Derogation Area counties in the 2015/16 season, rotation and price were still the major reasons provided for the reduction in area of WOSR grown. Rotation and price were also the most common reasons for farmers growing more WOSR in 2015/16 with the contradictory responses to price in this study difficult to explain. The main reasons given by the 20 farms that were not growing any WOSR in 2014/15 were "price" and "cabbage stem flea beetle".

3.2 Crop area lost to CSFB

Of the sampled growers in 2014/15, 17% were identified to have lost crop to CSFB which equates to 258.9 ha or 3% of the area grown. Weighted sample data estimates that nearly 16,000 ha were lost at a national level. There was considerable variation in area of crop lost by region (Table 3) from zero losses in some areas to an estimated 11% in Essex. Where crop loss was extensive and conditions allowed, some growers were able to re-drill the crop. Of the sample area lost (259 ha) some 152 ha were re-drilled i.e. 59% of the area initially lost. Given an estimate of 15,818 ha originally lost, of which 9,200 ha were re-drilled, leaves 6,604 ha of WOSR crop area completely lost to CSFB in 2014/15.

Of the 178 sampled growers that grew WOSR in 2015/16, 44 farms reported crop damage due to CSFB. Of these 45 farms with crop damage, 5 reported minimal damage and so recorded no loss of crop area to CSFB. The remaining 39 farms (19% of sampled farms) recorded a total area lost to CSFB of 419.4 ha (5% of area planted). Weighted sample data estimated that 28,759 ha i.e. 5% of the oilseed rape area grown in England was lost to CSFB in 2015/16 which was higher than the 3% recorded in the previous season. Where crop loss was extensive and

conditions allowed some growers were able to re-drill the crop. Of the 419 ha lost, some 333 ha (on 18 farms) was re-drilled, i.e. 79% of the area initially lost. The total area lost on the sample farms that was not re-drilled was 86 ha. Weighting up of sample data indicates that 22,912 ha were re-drilled across England. Given an estimate of 28,759 ha originally lost to CSFB, this leaves 5,847 ha of WOSR crop area completely lost compared with 6,604 ha in 2014/15.

The weighted area lost to CSFB varied considerably from zero losses in some counties to an estimated 18% of farms in Suffolk. The 13% losses in the merged counties of Northumberland and Durham were somewhat distorted by a single farm that lost 61% of the planted crop. All farms in the Derogation Area in 2015/16 reported some level of damage, whereas 19% of farms outside the DA reported no infestation or damage due to CSFB. Of the 28 farms surveyed in the DA there was no reported decrease in the level of pest infestation with the use of treated seed. Six farms commented that slugs were a greater problem for WOSR crops than CSFB.

3.3 Insecticide use against actual/potential risk of CSFB

In 2014/15, 82% of sampled growers reported using insecticide sprays against CSFB attacks (actual or predicted). Pyrethroids were by far the major insecticide group used to combat CSFB representing 87% of the area treated in 2014/15, with cypermethrin and lambda-cyhalothrin the major active substances used. In total 36 growers changed some agronomic practices in an attempt to reduce the impact of possible CSFB attack with increased spray applications and earlier drilling the major changes made followed by increased monitoring of crop and the use of autumn fertiliser. The sample area treated against CSFB was 19,729 ha in 2014/15 (Table 4) with crops on average being treated twice which equates to 1.14 million ha treated against CSFB at a national level. There were clear differences in area treated and the number of

applications between counties with 3.8 applications per crop in both Suffolk and the merged counties of Bedfordshire, Hertfordshire and Cambridgeshire.

In total 73 growers altered their agronomic practices in 2015/16 in an attempt to reduce the impact of possible CSFB attacks with earlier drilling date followed by increased spray applications the primary changes made. Of the 179 sample farms growing WOSR in 2015/16, 128 (71.9%) reported using insecticides to control CSFB. Pyrethroids accounted for 91% of total active substance used against CSFB with cypermethrin representing 60% of the total. Sample farms in 2015/16 used a total of 2,121 litres of foliar product against CSFB together with 76 kg of pymetrozine, thiacloprid and acetamiprid which are all applied as solids but overall account for only a small proportion of total insecticides used. The area treated against CSFB for the 2015/16 survey was much lower than in the previous season at 12,155 ha with a reduced number (1.4) of applications per crop (Table 4). The number of applications per crop was highest in Lincolnshire and North Yorkshire (2 .2 applications per crop) but lower in the DA counties of Suffolk (1.5) and the merged counties of Bedfordshire, Hertfordshire and Cambridgeshire (1.3) than in the previous 2014/15 season.

Within the DA counties in 2015/16 there was a clear difference in the number of insecticide applications per crop (Table 5) between neonicotinoid treated (1.0) and non neonicotinoid treated seed (1.9). Although these data must be viewed with caution due to the very low sample numbers (8 sample farms using treated and 15 using untreated seed). This difference was particularly noticeable in Suffolk which had 5.4 applications per crop where non neonicotinoid treated seed had been used compared with only 1.3 applications per crop when treated seed was used.

In 2015/16 only 18 of the sample farms had not used an agronomist for recommendations on insecticide and of these 5 were BASIS qualified (an independent registration scheme for the

UK pesticide industry) reflecting the high level of educational/practical knowledge pertaining to the farms used in this survey.

3.4 Estimated cost of CSFB to growers

This study estimates that the cost of CSFB control in WOSR England in 2014/15 was £22.2 million which includes the cost of agrochemicals (£7.8m), with a further £11.4m in cost of application. The 6,604 ha of crop area lost to CSFB and not re-drilled is estimated to have lost growers £2.3m (based on a commodity price of £340/t), with an additional cost of £0.7m for the re-drilling of 9,214 ha. In 2015/16 the cost of CSFB control was lower at £17.8m with the cost of agrochemicals down to £4.1m and the cost of application also reduced to £8.1m. The 5,847 ha of crop area lost to CSFB and not re-drilled is estimated to have cost growers £2.9m (based on a commodity price of £265/t) with an additional £2.6m for re-drilling of 22,912 ha.

4 DISCUSSION

4.1 Area reduction

The area of oilseed rape grown in England has decreased annually from a peak of 712,671 ha in 2011/12 to 542,807 ha in the 2015/16 season.[31] The current survey identifies reductions in WOSR area planted in England of 8.8% and 13% in the 2014/15 and 2015/16 seasons respectively which is consistent with official DEFRA figures. In both seasons the most common reason given for a change in oilseed rape area grown on sample farms was “crop rotation”, followed by “commodity price”, and then “cabbage stem flea beetle” which supports the conclusions for the reduction in oilseed rape area in the UK in recent years i.e. reduction in commodity price, increased costs of production and CSFB risk.[32] There were clear regional differences in changes in crop area in both the 2014/15 and 2015/16 seasons. Data at the county

level are only available in England every 3 years i.e. 2012/13 and 2015/16 with the DA counties of Bedfordshire, Hertfordshire and Cambridgeshire and Suffolk showing reductions in crop area of 29.4, 30.8, 35.8 and 15.8% respectively over the period compared with a national figure of 19.7% showing that with the exception of Suffolk the reduction in crop area was much higher in the DA counties. [28]

4.2 Crop loss to CSFB

Survey data identified a loss of 15,818 ha (3% of the area grown) to CSFB at a national level in 2014/15 with an increase to 28,759 (5% of area grown) in the following season. Crop losses varied considerably by county and even within DA counties where Suffolk had the highest recorded losses (18% of crop area) in 2015/16 (compared with zero in 2014/15). The other 3 merged Derogation Area counties i.e. Bedfordshire, Hertfordshire and Cambridgeshire reported a much lower amalgamated loss of 3% of crop area in 2015/16 compared with 9% in 2014/15. In both seasons high crop losses to CSFB were recorded in the East Riding of Yorkshire which supports the levels of CSFB larvae numbers recorded in East and North Yorkshire for autumn surveys carried out in 2014 and 2015. [33] The variation identified in this study between counties and seasons based on historical experience with infestation and crop damage makes integrated pest management approaches difficult to implement.

A live monitoring survey of damage caused by CSFB was also carried out in autumn of 2014/15 and 2015/16 (using a network of agronomists and covering 5% of total UK area in 2014/15 and 11% in 2015/16). The area of crop lost to CSFB was reported at 1% for 2015/16, [34] which was much lower than the 2.7% loss reported in the previous season.[35] Crop losses in the autumn 2015/16 survey were also highest in the eastern and southern regions. The losses reported were similar to the data reported from the current survey for 2014/15 but much lower than the 5%

reported in the 2015/16 survey. The differences in the results between the two studies especially in 2015/16 could partially be explained by the fact that assessment for the live monitoring surveys was done at the 3-4 leaf stage of crop growth and much earlier in the season than in the current study. In addition to which, the area lost to CSFB on sample farms in the current study (419 ha) may have been an over-estimate as, of the 44 farms that reported crop loss, 8 also acknowledged that the crop declared lost to CSFB may in part, have been due to slugs and a later drilling date than ideal.

An annual AHDB Market Intelligence Winter Planting Survey for 2014/15, included a number of additional questions to gather further evidence on the impact of the neonicotinoid seed dressing ban. [36] Over 1,300 WOSR growers, with crops equivalent to 8% of the national area in England and Wales, completed the survey based on planted areas as at 1 December 2014. Approximately 5.0% of the WOSR area originally planted was reported to have been lost to adult CSFB (higher than the 3% reported in this study) with about 1.5% of this area reported to have been successfully replanted which is the same as the level identified in the current study. The remaining 3.5% was estimated to be equivalent to 22,000 ha of oilseed rape crop area lost in England.

The variation in crop losses between counties and years is also supported by a survey of CSFB larvae carried out in the autumn of both 2014 and 2015 which showed high levels in the DA counties. [33] In 2014 Essex had the highest number of larvae per plant (>7) followed by the Bedfordshire, Cambridgeshire, Buckinghamshire and Suffolk while in 2015 Hertfordshire had the highest (>6 per plant) but was closely followed by Cambridgeshire, Bedfordshire, Essex (all >4 larvae per plant) and Suffolk (>3 larvae per plant).

4.3 Insecticide use to combat CSFB

Insecticides were used against CSFB on 82% and 72 % of farms respectively in 2014/15 and 2015/16 which is in close agreement with the 75% of area treated in the AHDB survey.[34] The synthetic pyrethroids, cypermethrin and lambda-cyhalothrin were the main products used, accounting for 60% and 18% of active substance use respectively in 2015/16. There were clear differences in treated area between counties and years. In 2014/15 highest number of applications per crop were in the Derogation Area and adjacent counties to these i.e. Norfolk, the merged counties of Kent, Essex, Sussex and Hampshire and the merged counties of Oxfordshire, Buckinghamshire and Berkshire. The lowest levels of treated area were generally in areas where reported losses were low thereby supporting the reactive use of sprays where and when pest attack is most likely.[37] There were clear differences in the area treated and in the number of applications within the DA where neonicotinoid treated seed compared with when non neonicotinoid seed was used (average of 1.0 versus 1.9 applications across both years). An increase in area treated to compensate for the seed dressing ban was also identified in an evaluation of its impact on pest management in oilseed rape across Europe. [38] From this current study 1.14 and 0.77 million hectares of WOSR was treated to combat the threat of CSFB in the autumn of 2014/15 and 2015/16 respectively. The clear difference between the two seasons can be partly explained by: the reduction in area of WOSR grown between the two seasons, the presence of a DA in 2015/16 with clear differences for farms using treated versus non-neonicotinoid treated seed and awareness of increasing resistance of CSFB to pyrethroids. Resistance of CSFB to pyrethroids was first identified in Germany in 2008,[39] with resistance now becoming widespread throughout Europe and the UK,[7] but is partial, so growers still get some level of control. The reduced susceptibility of CSFB in Germany is associated with a *kdr* (L1014F) target site resistance mutation, which is also common in other pyrethroid resistant insect species.[40] A study of 30 CSFB samples taken from fields in seven different counties

(primarily in the south-east) in England in 2014 suggested the presence of a metabolic-based resistance mechanism in addition to the *kdr* target site mutation.[7]

The Pesticide Usage Survey (PUS) records data for pesticide use on arable crops in the UK and is published in alternate years i.e. harvest years 2012, 2014 and 2016.[41, 2, 42] The 2016 survey therefore provides the first data available on insecticide use on oilseed rape since the ban on neonicotinoid seed dressings was introduced. Insecticide use on oilseed rape in the UK was recorded as 35.6, 28.3 and 24.6 tonnes a.s. in 2012, 2014 and 2016 respectively. [40, 2, 41] The reduction in active substance applied between 2014 and 2016 of 13% is explained by the 14.2% reduction in UK crop area between the two years.[31] However, a clear difference in autumn vs spring split was evident from the PUS with 58% of insecticide use in the autumn of 2016 compared with only 37 and 39% in 2012 and 2014 respectively (David Garthwaite *pers. comm.*). The increased use of autumn insecticides in 2016 was attributed to the increased risk of CSFB, where 58% of insecticide treatments were used to control the pest compared with only 28% in 2012 and 27% in 2014. [41, 2, 42]

4.4 Financial implications of CSFB control

The financial cost of CSFB in England was lower in 2015/16 at £17.8m than in 2015 (£22.2m) primarily associated with a reduced area treated. The cost of agrochemicals used was lower at £4.1m (down from £7.8m in 2014/15) with the cost of application also down at £8.1m (£11.4m in 2014/15). The 5,847 ha of crop area lost to CSFB in 2015/16 and not re-drilled is estimated to have lost growers £2.9m (slightly higher than the £2.3m in 2014/15) and the increased area of 22,912 ha that was lost to CSFB and then re-drilled is estimated to have cost a further £2.6m which is much higher than the £0.7m in the previous season. These financial costs do not take into account the potential saving to farmers of not using a neonicotinoid seed dressing. In

addition the study does not take account of the amount of pyrethroids used in years prior to the neonicotinoid seed dressing ban which would be needed to identify the net cost of the ban on oilseed rape production costs in England. The increased costs to farmers reported in this study also confirm the findings of Budge,[20] who showed that farmers who use neonicotinoid seed dressings on oilseed rape reduce the number of subsequent applications of foliar insecticide sprays and may derive improved economic return.

5 CONCLUSIONS

The oilseed rape area in England has fallen for the fourth successive year from a peak of 712,671 ha in 2011/12. Although CSFB was not the main reason given by farmers for the reduction in area it has clearly been a contributory factor as the area reduction in high risk areas has been greater than in other parts of the country. Crop losses of 3% in 2014/15 and 5% in 2015/16 are slightly higher than recorded in other studies investigating the impacts of CSFB on oilseed rape and are likely in part because of the later assessment date in this study. There are clear high risk areas for the presence of CSFB and the damage that the pest causes with Cambridgeshire, Bedfordshire, Hertfordshire and Suffolk having clearly been identified in the past via inclusion in the Derogation Area for 2015/16. The current study shows that there is clear site and season variation which makes CSFB damage difficult to predict based on historical experience therefore making integrated pest management very difficult.

There was a reduction in the area treated and the number of applications per crop to combat CSFB in the two seasons with a clear reduction in 2015/16 compared to 2014/15 and clear differences between counties. Within the DA counties there was a clear reduction in the number of applications per crop when neonicotinoid treated versus non treated seed had been used i.e. 1.0 vs 1.9 respectively. The financial cost of CSFB control in England was lower in 2015/16

than in the previous season (£17.8m vs £22.2m) largely due to a reduced area treated with insecticide. Increasing resistance to pyrethroid insecticides in combination with a continuation of the neonicotinoid seed dressing ban for oilseed rape is likely to have significant impacts on the viability of growing oilseed rape particularly in parts of the country where CSFB activity is high**.** It is also likely that the loss of oilseed rape from the rotation will result in the inability of some farms to find a profitable replacement crop thus impacting overall farm profitability.

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Table 1. Farm sample distribution by merged county in 2014/15 and 2015/16.

Merged Counties	**Number of sampled farms 2014/15**	**Sample Area (ha)**	**Weighted crop area (ha)***	**% area grown 2014/15**	**Number of sampled farms 2015/16**	**Sample Area (ha)**	**Weighted crop area (ha)***	**% area grown 2015/16**
Bedfordshire, Hertfordshire, Cambridgeshire	20	927	53,874	10	18	1,216	72,706	14
Cheshire, Staffordshire, Shropshire	10	323	20,296	3	12	329	21,058	4
Derbyshire, Leicestershire, Nottinghamshire, Northamptonshire	19	607	37,787	6	19	588	39,291	7
Dorset, Devon, Cornwall	12	409	25,775	4	12	317	21,324	4
East Riding of Yorkshire	11	266	16,860	3	11	339	29,754	6
Gloucestershire, Wiltshire, Somerset	11	947	55,012	10	13	624	37,707	7
Herefordshire, Worcestershire, Warwickshire	12	330	20,781	3	13	320	20,537	4
Kent, Essex, Sussex, Hampshire	24	1,376	78,112	14	20	925	61,320	11
Lincolnshire	24	1,040	61,552	11	23	1,000	64,308	12
Norfolk	14	763	43,481	8	14	500	29,149	5
North Yorkshire	12	229	14,536	2	11	229	16,569	3
Northumberland, Durham	12	422	28,492	4	14	402	25,780	5
Oxfordshire, Buckinghamshire, Berkshire	13	1,159	66,684	12	14	1,121	65,346	12
Suffolk	11	946	53,503	10	9	465	29,200	5
Total	**205**	**9,744**	**576,744**	**-**	**203**	**8,375**	**534,047**	**-**

* The sample data were weighted up to national level using weights calculated from the 2013 June survey population data for 2014/15 and from the 2015 June survey population data for 2015/16. [23,24]

Table 2. Sample and weighted changes in winter oilseed rape cropping area (ha) for 2014/15 and 2015/16 by merged county.

Merged counties	**Sample net change in area 2014/15**	**Weighted net change in area 2014/15**	**% change**	**Sample net change in area 2015/16**	**Weighted net change in area 2015/16**	**% change**
Bedfordshire, Hertfordshire, Cambridgeshire	-231.8	-13,748	-20.0	-172.9	-14,131	-12.4
Cheshire, Staffordshire, Shropshire	2.1	129	+0.6	-36.8	-2,303	-10.1
Derbyshire, Leicestershire, Nottinghamshire, Northamptonshire	-83.9	-6,393	-12.1	-39	-2,771	-6.2
Dorset, Devon, Cornwall	-137.5	-8,161	-25.1	-59.1	-3,722	-15.7
East Riding of Yorkshire	-5.3	-407	-2.0	-89.9	-3,936	-21.0
Gloucestershire, Wiltshire, Somerset	-19.0	-1,232	-2.0	71.9	2,538	+13.0
Herefordshire, Worcestershire, Warwickshire	-47.7	-3,300	-12.6	-47.2	-2,597	-12.8
Kent, Essex, Sussex, Hampshire	-123.1	-7,457	-8.2	-243.6	-16,794	-20.8
Lincolnshire	-106.6	-6,199	-9.3	-24.2	-2,270	-2.3
Norfolk	-215.4	-11,992	-22.0	50.8	1,711	+10.2
North Yorkshire	-39.5	-2,622	-14.7	0.4	117	+0.2
Northumberland, Durham	13.0	1,414	+3.1	-73.2	-5,343	-15.4
Oxfordshire, Buckinghamshire, Berkshire	30.5	1,822	+2.7	-195.0	-10,920	-14.8
Suffolk	84.5	4,900	+9.8	-158.1	-9,320	-25.4
Total	**-879.6**	**-53,248**	**-8.3**	**-1,016.0**	**-69,741**	**-10.8**

- Indicates a reduction in crop are

Table 3. Sample and weighted crop losses (ha) to CSFB in 2014/15 and 2015/16 by merged county.

Merged Counties	**Nº. of sampled farms with crop loss to CSFB 2014/15**	**Area lost on sample farms 2014/15**	**Weighted area lost 2014/15**	**% of weighted area lost 2014/15**	**Nº. of sampled farms with crop loss to CSFB 2015/16**	**Area lost on sample farms 2015/16**	**Weighted area lost 2015/16**	**% of weighted area lost 2015/16**
Bedfordshire, Hertfordshire, Cambridgeshire	5	69.4	4593.7	9	4	24.5	1835.7	3
Cheshire, Staffordshire, Shropshire	1	9.3	725.2	4	1	0.3	15.0	0
Derbyshire, Leicestershire, Nottinghamshire, Northamptonshire	1	0.4	27.3	<1	2	3.4	206.3	1
Dorset, Devon, Cornwall	1	0.1	7.4	<1	1	9.1	790.4	4
East Riding of Yorkshire	2	13.4	969.7	5	2	43.2	3678.1	12
Gloucestershire, Wiltshire, Somerset	4	42.5	2319.6	4	1	5.0	372.6	1
Herefordshire, Worcestershire, Warwickshire	0	0	0	0	0	0	0	0
Kent, Essex, Sussex, Hampshire	6	70.79	4026.9	5	5	56.7	3830.5	6
Lincolnshire	8	41.2	2411.7	4	6	25.6	1875.4	3
Norfolk	1	1.5	91.6	<1	4	48.0	2671.4	9
North Yorkshire	1	2.0	136.4	1	5	19.0	1241.6	7
Northumberland, Durham	1	0.2	14.66	<1	3	55.2	3376.9	13
Oxfordshire, Buckinghamshire, Berkshire	1	8.1	494.1	1	7	54.5	3473.1	5
Suffolk	0	0	0	0	3	75.0	5391.9	18
Total	**32**	**258.9**	**15,818.3**	**3**	**44**	**419.4**	**28,758.9**	**5**

Table 4. Area sprayed (ha) against CSFB in England for 2014/15 and 2015/16 by merged county.

	2014/15			**2015/16**		
Merged counties	**Sample area treated (ha)**	**Weighted area treated (ha)**	**Nº. of applications**	**Sample area treated (ha)**	**Weighted area treated (ha)**	**Nº. of applications**
Bedfordshire, Hertfordshire, Cambridgeshire	3,519	204,682	3.8	1,543	100,145	1.3
Cheshire, Staffordshire, Shropshire	314	19,763	1.0	265	18,547	0.8
Derbyshire, Leicestershire, Nottinghamshire, Northamptonshire	717	43,973	1.2	783	53,018	1.3
Dorset, Devon, Cornwall	374	23,957	0.9	378	24,993	1.2
East Riding of Yorkshire	392	25,268	1.5	562	41,444	1.7
Gloucestershire, Wiltshire, Somerset	1,281	73,838	1.4	422	26,956	0.6
Herefordshire, Worcestershire, Warwickshire	370	22,385	1.1	177	10,276	0.6
Kent, Essex, Sussex, Hampshire	2,810	160,817	2.0	1,200	81,109	1.3
Lincolnshire	1,255	75,167	1.2	2,172	136,350	2.2
Norfolk	2,274	126,980	3.0	830	44,431	1.7
North Yorkshire	344	22,132	1.5	495	34,158	2.2
Northumberland, Durham	445	28,516	1.0	586	36,053	1.5
Oxfordshire, Buckinghamshire, Berkshire	2,009	114,197	1.7	1,640	97,213	1.5
Suffolk	3,624	203,049	3.8	1102	63,435	1.5
Total	**19,729**	**1,144,725**	**2.0**	**12,155**	**768,127**	**1.4**

Table 5. Sample area treated and number of applications for neonicotinoid treated and non neonicotinoid treated seed within Derogation Area counties in 2015/16

Merged counties	**Non neonicotinoid treated seed**			**Neonicotinoid treated seed**		
	Sample area (ha)	**Area treated (ha)**	**Nº. of applications**	**Sample area (ha)**	**Area treated (ha)**	**Nº. of applications**
Bedfordshire, Hertfordshire, Cambridgeshire	985	1,399	1.4	230	144	0.6
Suffolk	125	676	5.4	340	426	1.3
Total/mean	**1,110**	**2,075**	**1.9**	**570**	**570**	**1.0**

Table S1. Survey questionnaire used in 2015/16

	Winter Oilseed rape plantings autumn 2015	farm number	
1.1	What area of WOSR did you plant in autumn 2015?		ha
1.2	How much did you grow last year (2015 harvest)?		ha
2	If this differs, in broad terms, from last year why? (please list up to 4 reasons)		
3	**Question 3 applies only to the derogation area; Bedfordshire, Cambridgeshire, Hertfordshire & Suffolk**		
3.1	Did you request neonicotinoid treated seed?		
		ha	Kg
3.2	If so, how much?		
3.3	How much did you get?		
4.1	Did you use/employ an agronomist for your WOSR Cabbage Stem Flea Beetle (CSFB) insecticide recommendations? (yes or no)		
	Any comment?		
		on area planted with seed NOT TREATED WITH NEONICOTINOID	
4.2	Was pest incidence/damage greater in this crop than in the previous season? (same, greater, less, no damage)		
	Any comment?		
5.1	Did you use any insecticides **SPECIFICALLY** to combat actual or predicted CSFB attacks? (yes or no)		
5.2	Did you change agronomic practices to avert possible CSFB damage? If so please list up to 4		
		chemical 1	
6.a	If chemicals were used **SPECIFICALLY** against CSFB which ones?	chemical name	
7.a	What rate were the insecticides applied at?	application rate litre/ha or gm/ha	
8.1.a	What area was treated?	area (ha)	
8.2.a	(If multiple applications please record areas and incidence; e.g. 40ha x 3 applications)	number of applications	
8.3.a	If the same chemical (in q 6) is	area (ha)	

	used at the same rate		
8.4.a	for different areas or a different number of applications please use these cells	number of applications	
8.5.a	If the same chemical (in q 6) is used at the same rate	area (ha)	
8.6.a	for different areas or a different number of applications please use these cells	number of applications	

		chemical 2
6.b	chemical	
7.b	application rate litre/ha or	
8.1.b	area (ha)	
8.2.b	number of	
8.3.b	area (ha)	
8.4.b	number of	
8.5.b	area (ha)	
8.6.b	number of	

		chemical 3
6.c	chemical name	
7.c	application rate litre/ha or gm/ha	
8.1.c	area (ha)	
8.2.c	number of applications	
8.3.c	area (ha)	
8.4.c	number of applications	
8.5.c	area (ha)	
8.6.c	number of applications	

		chemical 4
6.d	chemical name	
7.d	application rate litre/ha or gm/ha	
8.1.d	area (ha)	
8.2.d	number of applications	
8.3.d	area (ha)	
8.4.d	number of applications	
8.5.d	area (ha)	
8.6.d	number of applications	

9	Despite the use of insecticide did you lose any crop area due to CSFB? (yes or no)	
	Any comment?	
10	If so, what area? (ha)	
11	Was any CSFB crop damage so severe that you have had to redrill? (yes or no)	
	Any comment?	

12	If so what area? (ha)	

Any further comments

Fig 1. Geographical location of the counties of England


Northumberland
Durham
Cumbria
North Yorkshire
East Riding of Yorkshire
Lancashire
West Yorkshire
South Yorkshire
Cheshire
Derbyshire
Notts.
Lincolnshire
Staffordshire
Shropshire
Leics.
Norfolk
Worcs.
Warks.
Northants.
Cambs.
Suffolk
Herefordshire
Beds.
Gloucestershire
Oxon.
Bucks.
Herts.
Essex
Berkshire
Wiltshire
Somerset
Hampshire
Surrey
Kent
Sussex
Devon
Dorset
Cornwall