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Field monitoring of BYDV risk in winter cereals (pilot study)

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CONTENTS

1. Abstract

This project explored the potential to develop a field-based monitoring approach to help predict the risk of *Barley yellow dwarf virus* (BYDV) transmitted by cereal aphids in the autumn.

As part of a literature review, the project appraised BYDV decision support tools (DSTs). This identified two models and DSTs developed in the UK that could provide a basis for a new BYDV support service. However, the availability of the full documentation and/or code needs verifying and refining, especially with respect to a field monitoring system linked to yield loss estimates.

A survey of farmers and agronomists identified a high potential (92% of respondents) for adoption of a farm-based tool that integrates risk factors with current and refined practices, such as the use of weather data and monitoring at field and wider scales.

A field-specific monitoring method, based on yellow sticky traps mounted horizontally (just above the crop), was developed and evaluated. This aimed to determine: a) predictive capabilities of the method, b) practicalities of use by farmers and agronomists, c) whether landscape composition, boundary or tillage type affect immigration of aphid vectors. The sticky traps were effective at sampling winged cereal aphids. A 20 x 20 cm trap was sufficient to identify differences within and between fields. In a small plot trial, numbers of bird cherry-oat aphids caught on sticky traps was negatively related to yield. However, because of low plant colonisation, predictive capabilities, with respect to crop aphid infestation levels and BYDV, could not be tested. Trials of the sticky trap system by farmers and agronomists showed that aphid identification skills need improving. However, even with minimal training, people could detect aphid trends. All trial participants and 90% of survey respondents expressed willingness to monitor sticky traps on a weekly basis, on approximately four fields per farm. Across all studies, traps captured at least three times as many cereal aphids in the headland areas of fields, especially next to taller field boundaries. This indicates that wind currents determined aphid immigration patterns within fields. Such spatial pattern offers the opportunity to spray headland areas only to reduce insecticide usage. However, research needs to confirm the impact on whole field populations and BYDV infection, accommodate pesticide application restrictions and investigate the threat to boundary overwintering invertebrates. Considerable variation was found in levels of immigrating aphids between fields (24% of fields had no aphid immigration), even on the same farm. This confirms the merit of a field-based monitoring system to reduce insecticide usage. Landscape composition influenced levels of immigrating grain aphids, with grassland increasing levels. The type of tillage had no impact on levels of immigrating winged aphids. This shows that deposition was passive, determined by wind vortices, rather than by active selection during flight. Less than 5% of aphids were infected with BYDV.

2. Introduction

BYDV is transmitted to cereal crops predominantly in the autumn by cereal aphids (bird cherry – oat aphids and grain aphids) that either migrate into the crop from surrounding habitats or that survive from the previous crop on a green bridge. Aphid flight usually stops when temperatures drop below 11°C. Secondary spread by wingless aphids is responsible for BYDV incidence within the crop and is strongly correlated with number of day degrees. The second generation of wingless aphids is produced after 170 day-degrees when the temperature is above 3°C each day. Neonicotinoid seed dressings have been the primary method of controlling the aphid vectors since they were introduced in the mid-1990s, prior to their withdrawal in the UK in 2018. They were considered to provide approximately 6 weeks control from drilling after which a foliar applied pyrethroid insecticide could be applied. At present the suction trap network run by Rothamsted Research provides information on regional aphid levels which are provided in the AHDB's Aphid News. However, the advice is to only apply foliar insecticides after finding them in the crop. Timing of foliar insecticides to coincide with the emergence of the second generation of wingless aphids can be achieved using T-sum which uses local weather data to calculate when 170 day-degrees has been reached. This tool is available on the AHDB website and other providers, like Agrii, as a mobile phone or web app. T-sum is started either on the day of crop emergence or following a foliar spray taking into account duration of protection provided by the product persistence.

The risk of BYDV infection in the autumn is likely to rise in the short term owing to the withdrawal of three neonicotinoid insecticides routinely used as seed dressings. In the longer term, rising global temperatures will allow aphids to be more active in winter increasing the risk and spread of BYDV. Indeed, the latest predictions are that losses caused by insect pests in wheat in the UK will rise by at least 50% by 2050, but the total yield could be reduced by three times as much reaching 22% (Deutsch et al. 2018).

Previous studies in the UK (Harrington et al., 1999) showed that BYDV infection varies between regions, with coastal areas having a higher risk, and between fields (of 623 fields 28% tested positive over 3 years). One of the factors that influences aphid levels is landscape composition with more where there is uncropped land such as grassland, moorland, wasteland and virus levels were lower where arable land dominates (Harrington et al., 1999). Many perennial and annual grasses are infected with BYDV (Ingwell et al. 2017), but wild grasses with the exception of Annual meadow grass are considered poor sources of the virus (Masterman et al. 1994). A recent French study found that colonization was reduced when grassland cover in the landscape was high, but also increased when there was more maize in the surrounding 1 km radius circle (Gilabert et al. 2017). Climate warming may lead to maize being grown further north in the UK. Other important agronomic factors affecting likely infection are field aspect, field size and soil type but the latter may be correlated with geographic region and crop weediness. Minimum tillage may also affect initial aphid immigration (Kendall et al. 1991) either because the crop debris disguises crops spectral reflectance and thereby attractiveness to winged aphids or because there are more natural enemies that prevent the build-up and spread of aphids. The extra debris may offer more opportunities for web-spinning spiders (e.g. Linyphiidae) that can help control aphid infestations. Current GWCT studies in winter cereals showed that these are higher where minimum tillage is used but their contribution to aphid control has not been quantified. Such spiders are, however, highly susceptible to autumn-applied pyrethroid insecticides (Pullen et al. 1992). These factors are influential because aphids are capable of directing where they land (Parry et al. 2015) and select crops as opposed to semi-natural habitats (Favret & Voegtlin 2001). They are also more likely to land at the edge of the crop because the plant-soil boundary reflects long-wavelength light, which is attractive to aphids (Schroder et al. 2015). Deposition may also be influenced by local wind currents around boundary features. Consequently, aphid infestation levels can vary considerably between fields and even within fields however there is still uncertainty over the level of interaction from semi-natural habitats with the crop for both virus and vectors. Virus transmission rates between plant host and aphids varies between host and aphid species and between years (Masterman et al., 1994).

The suction trap network which is currently the only source of monitoring is not evenly spread across the main arable production areas. A small study conducted in late 1990s showed a strong correlation between aphid capture on sticky wire traps located at 250 m, 750 m and 39 km from one suction trap (Harrington & al. 1999). The area over which data from the aphid sampling network is relevant is unknown although if based on an effective range of 40 km would cover less than one sixth of the cereal area in the UK. Consequently, the relevance of aphid distribution data provided by the suction trap network to farmers located greater than 39km from the nearest trap is uncertain and was first questioned in the 1980s (Kendall & Smith, 1981; Tones & Bassett 1988). A more reliable estimate was provided by using a crop vector index that combined BYDV infectivity with aphid abundance obtained from sampling the crop (Kendall et al. 1992). They showed that colonization of cereals in the autumn by winged immigrants was variable and even more variable was the subsequent spread by their unwinged progeny, and thus subsequent levels were frequently unrelated to the aerial density of migrant vectors measured by the suction traps. This was unsurprising given the complex array of meteorological and agronomic factors that determine their initial infestation and subsequent survival. Since that period no alternative monitoring systems have been developed, in part because of the introduction of neonicotinoid seed dressings that provided reliable control for up to 6 weeks after drilling. Moreover, the suction trap network only provides information on numbers of aphids being sampled and their trend but not whether the levels pose a threat to crops. For the first time, in 2019 a small number of cereal aphids are also being tested for BYDV infection. Given the high variation in aphid levels and potentially virus too, there is a need to develop a field-based monitoring system.

In-field monitoring systems, such as the use of sticky traps, are already used for some crop pests including pollen beetle (Ellis et al., 2018) and carrot root fly (Collier et al. 2008). Recent GWCT studies using yellow sticky traps located horizontally on the ground were effective for sampling alate (winged) cereal aphids (Holland et al., 2019). These studies also compared infestation levels for 14 landscapes that differed in the proportion of semi-natural habitats. They revealed considerable variation in aphid infestation levels between fields and that deposition was highest within 8 m of hedgerows/woodland and was twice as high on the downwind compared to upwind side in winter cereals in the autumn. Boundary height had no effect on deposition.

This previous study confirmed that sticky traps can effectively collect aphids during the autumn/winter period and that they are sufficiently sensitive to show differences between sampling locations within and between fields. Knowing the number of invading aphids and the timing of their appearance is crucial if an improved Decision Support Tool (DST) is to be developed. Even so insecticide usage can be reduced using the existing T-sum tools as in some cases temperatures drop and T-sum is not triggered. It can also improve the timing of foliar insecticide applications to ensure their effectiveness. Further reductions could also be achieved if an aphid economic injury level and thereon a spray threshold could be developed. At present there is no UK-validated field-based thresholds that farmers can use to determine whether insecticide treatments are necessary for autumn- or spring-sown cereals. However, a study in northern France found that use of autumn infection levels of bird cherry-oat aphid could be used to predict yield loss caused by BYDV with the model having 74-91% accuracy (Fabre et al. 2003). These authors concluded that although the accuracy of the model may be improved with knowledge of BYDV infectivity in aphids, because the virus rather than aphid feeding was the main cause of damage, this was not needed. This is because the cost of potential damage is more than four times the cost of treatment therefore a highly sensitive (cautious) method is needed and assessing aphids alone will achieve this. Moreover, the costs of virus detection are high (approx. £10/aphid using PCR) and even if reduced and made simple, would still require considerable numbers of aphids to be collected and tested as typically only 10% or less contain the virus. The French study identified a threshold of three aphids per plant but assessing aphid levels in the crop is not simple and is time consuming, whilst the accuracy is influenced by weather conditions as this affects the aphids and how visible they are (Harrington et al., 1999) and consequently this adds some unreliability. The use of traps that collect aphids over time can provide an easier way for farmers/agronomists to monitor crops as tested for monitoring carrot root fly (Collier et al. 2008).

Following the withdrawal of three neonicotinoid seed dressings in December 2018, there is likely to be greater use of foliar applications of pyrethroid insecticides. With resistance to some pyrethroids already present in grain aphids (Foster et al. 2014), this poses a threat to their long-term viability. It is therefore vital that a monitoring system is developed quickly to optimise use as part of an IPM programme. Several different mathematical models have been developed to predict BYDV infection levels in the UK and France (Jones et al. 2010) and to predict aphid movement or time of arrival (Parry 2013), but none are capable of providing predictions of infestation at a field level. There have also been many other attempts to develop a Decision Support Tool (DST) that can help reduce the need for agrochemical interventions. At present 395 different crop production tools are available for farmers and advisers in the UK, with 76 currently in use (Rose et al. 2016). A farmer survey by Rose et al. (2016) revealed that 49% used some type of DST of which software (28%), paper-based (22%) and apps (10%) were the most useful. Usage by advisers was higher. Fifteen factors were identified that would influence uptake by farmers and advisers notably that they were quick, easy to use tools that gave an instant output decision for their farm and would benefit their business financially. Given the progress in information and communications technology (ICT), data collection and remote sensing technology there may be opportunities to develop suitable tools for predicting BYDV in the future (Janssen et al. 2017).

Overall there has been little research in recent decades on BYDV management worldwide, especially in countries where it can be problematic, because of the reliance of neonicotinoid seed dressings and changes in management (UK, Italy and Australia), although BYDV still causes problems in northern USA (Walls et al., 2019). In the USA, existing BYDV simulation models have been incorporated in a decision support platform indicating the potential for such an approach in the UK (Walls et al., 2016).

Aims and objectives

The overall aim of this pilot project was to examine the potential for developing a field-based monitoring approach to form part of a DST to predict the risk of BYDV.

The specific objectives were:

1. To assess the feasibility of developing a field-specific decision support system for BYDV.
2. To evaluate the practicalities of using a field-specific monitoring methodology for aphid vectors of BYDV and use of a T-sum-based tool to predict spray timings and the impact on BYDV infection levels.
3. To test whether landscape composition, boundary type and type of tillage effect immigration of aphid vectors.
4. To provide key messages for farmers to improve their knowledge and approach to BYDV management.
5. To provide recommendations on further research needed to develop field specific monitoring and a decision support system.

3. Materials and methods

3.1. Review of decision tools for BYDV

3.1.1. Literature review

A literature review was performed to identify:

- the potential for applying or adapting already published decision support tools;
- existing practices for the management of aphids and BYDV with a specific focus on IPM.

Two searches were performed on two bibliographic databases: Web of Science and FAO Agris.

The following combination of keywords were used:

- (BYDV OR Barley Yellow Dwarf Virus) AND
  (model OR simulation OR prediction OR forecast OR risk OR Decision Support System OR DSS OR Decision Support)
- (BYDV OR Barley Yellow Dwarf Virus) AND
  (control OR mitigation OR management OR integrated pest management OR IPM)

Based on the content of the abstract, the following criteria were adopted for including papers into the review:

- Decision support tools: papers should describe models/ decision support tools simulating the dynamic of the aphid vectors population during the autumn/winter and/or of the spread/risk for BYDV to spread, and/or quantifying the potential yield loss. Papers were also selected if they referred to epidemiological work which could have been of relevance for decision support.
- Management Practices: papers should describe the results from research investigating the effect on BYVD of management actions, other than the application of insecticide.

Reasons for discarding papers were that the above criteria were not met (no relevance), detailed information which could allow the replication of the work was absent and being written in a language other than English. Six papers were not retrievable.

Papers included in the review were described according to their relevant characteristics, such as:

- Decision support tools:
  - Year of Publication
  - Aphid species considered
  - Simulation of BYDV
  - Decision supported
  - Decision supported (Other)
  - Type of model

    - Model inputs
    - Other inputs
    - Temporal Input details
    - Model output
    - Other Output
    - Temporal Output details
    - Full algorithms available
    - Validation with independent data
    - Continent of development/validation
    - Country of development/validation
    - Applicability to the UK
    - Status of Applicability
    - Info on further research needed
    - Accessibility
    - Implementation status
    - Suitable for future project
    - Justification for non-suitability
    - General notes

- Management practices
    - ID
    - Year of Publication
    - Aphid species considered
    - Spread of BYDV
    - Practice/features considered
    - Other Practice/features
    - Continent of reference
    - Country of reference
    - Suitable for IPM
    - Suitable for DTS
    - Justification for non-suitability
    - General notes

3.1.2. Survey of farmers and agronomists

A survey was carried out which aimed to:

- Record current practice (eventually to be compared to those commonly used in 5-10 years' time).
- Assess farmers/agronomists needs in terms of decision support for aphid management following the withdrawal of neonicotinoid seed treatment in winter cereals.

The questionnaire (Appendix II) was prepared using the software SurveyMonkey and delivered online.

It was circulated via email among AHDB levy payers, Agrii agronomists and farmers, and via social media.

The questionnaire was published on 5th December 2018 and closed on 31st January 2019.

3.2. Evaluation of field-specific monitoring methodology of aphid vectors of BYDV

3.2.1. Predictive capability of aphid monitoring

A double-plot (3 x 10 m) trial was carried out by Agrii at Throws Farm in Essex. The winter barley variety California was drilled on the 18 September 2018 with no seed dressing and established using Sumo Trio (sub-soiler and discs). The trial focused on evaluating the effect of foliar insecticide treatment on subsequent development of BYDV, triggered by phenology, T-sum or an aphid threshold. The trials included the following four treatments all replicated 4 times in a randomised block experimental design: 1) untreated control; 2) spray timing according to standard practice (phenology driven at GS12); 3) T-sum 170 following crop emergence; 4) spray timing based upon threshold of three aphids per plant (Fabre et al. 2003) and use of Agrii App T-sum following threshold being reached.

The numbers of aphids invading the plots was low and failed to reach the threshold of three aphids per plant and therefore treatment 4 was not sprayed with insecticide. Treatment 3 was also not sprayed as the T-sum threshold was not triggered. Treatment 2 was sprayed with Argent (50 ml) (a.i.= lambda-cyhalothrin, 100 g/l) on 16/10/19 when the crop was at GS12. Data was therefore analysed using ANOVA as two treatments (untreated and treated) with plot as a blocking factor. Data for % BYDV was Asin square root transformed and that for aphids was log transformed (+1) to normalise the data.

In each plot, levels of alate and apterous aphids and species were monitored at weekly intervals on 25 plants per plot from mid-October till the first week of December. Yellow sticky traps (20 x 20 cm)

coated with ‘Wetstick’ (manufacturer Oecos ltd, Hertfordshire, UK) were also deployed during this period. The traps were mounted horizontally at ground level, two per plot located centrally 5 m apart. Plots were inspected on 5/4/19 and the proportion of plants infected with BYDV recorded. Plots were harvested on 22/7/19 and yield and Specific Weight (kg/hl) measured.
Data was analysed using one-way ANOVA with plot as a blocking factor using Genstat. Correlations between crop yield and quality measures, levels of BYDV and aphid infestation level were investigated using linear regression.

3.2.2. Reliability and practicalities of the sticky trap approach

Farm trials using unsprayed plots

If an in-crop, field specific vector monitoring system is to be developed and used to predict the threat of BYDV then the relationship between initial measured aphid infestation levels and the incidence of BYDV will have to be verified. To further support the trial conducted in 3.2.1 studies were conducted in six fields in Kent and four in Wiltshire. In Kent, only one field was treated with neonicotinoid seed dressing and the headland area (at least 10 m wide) of all fields was not treated with foliar insecticide. Two sticky traps were deployed in each area per field and numbers of cereal aphids assessed on 25 plants within 5 m of each sticky trap. Traps were changed weekly until when weather conditions become too cold for aphid flight. In Wiltshire, an unsprayed strip 24 m wide and 50 m long was located 40-90 m from the boundary in each of the four fields. In Wiltshire one sticky trap was deployed per area. Levels of BYDV infection were measured from visual assessments of crop damage in March at both sites. The treated and untreated areas in Wiltshire trial was also sampled for aphids and natural enemies using a Dvac suction sampler on 7/11/18, four 0.5 m^2 samples per area. For all sticky traps numbers of cereal aphids and natural enemies were assessed.

Farmer trials of sticky traps

If sticky traps are to be used routinely by farmers and agronomists to monitor aphids it is imperative that they can accurately identify aphids on the traps and that the methodology is robust, simple and easy to use. At present Oecos Ltd are the main producer of sticky traps to agriculture and make traps that are suitable for use within fields being stiff enough to withstand wind. Oecos supply these traps with either a wet or dry stick coating, in two sizes (10x20 cm, 20x20 cm, 20x40 cm) and three colours (yellow, white and blue). Traps can also be printed with a grid to make counting easier. After consultation with Oecos we selected the wet stick, yellow traps (20x20 cm) as yellow is known to be attractive to aphids and wet stick is the most rain-resistant coating. The traps were coated with wet stick on one side. In the field, traps were mounted on two trial pegs just above the crop and after deployment were stored individually within an A4 polypropylene sleeve typically used for protecting documents. The cost of the whole system was approximately £1 per trap. The same system was used in all of the other studies conducted in this project. The sticky traps were preserved by freezing until assessments could be made.

To test likely adoption by farmers and agronomists, the sticky trap system was trialled on 10 commercial farms and in 41 fields during autumn 2018 (Table 1). On each farm two sticky traps were deployed in winter cereal fields (one in the headland the other at least 70m from the crop edge). The users were provided with a simple guide (Appendix III) on how to identify aphids and asked to record the numbers they observed on each trap once collected. Only basic training was provided as we wanted to assess the current level of knowledge and thereby whether more detailed training would be needed in the future. Traps were deployed for 7-17 days, although most were replaced weekly, from GS12 until weather conditions become too cold for aphid flight (total trapping period across all farms 23 Oct to 10 Dec 2018). The traps were deployed in fields of varying aspect and established using different cultivation techniques (direct drill, minimum tillage or ploughed).

To assess the accuracy of the users, their aphid traps were also assessed by an experienced entomologists and results compared using Spearman's Rank correlation test.

Following completion of the trials, four farmers and two agronomists were interviewed to gain feedback on the system. They were asked questions about the practicalities of the approach, their aphid identification skills and whether it had influenced their decision making (Annex IV).

Information on the type of tillage system used to establish crop was also obtained and classified as ploughing, minimum tillage or direct drilling. To determine whether the type of tillage was influencing aphid immigration and whether this differed with distance from the field boundary the number of winged aphids (total winged aphids, grain aphids, or bird cherry-oat aphids) was modelled, using a Poisson distributed Generalized Mixed Linear Model (GLMM), against the fixed effects cultivation type (a three level factor) and trap location (a two level factor). To account for spatial and temporal pseudoreplication present in the data the nested random effects structure Farm/Field/Week was included in all models. Model fit and dispersion were investigated and where overdispersion was present in the data a random intercept was added to the model. Analysis was conducted in R using the package lme4. Only traps (205) which were left in the field for 7 days were included in this analysis.

Within-field spatial variation of immigrating winged aphids

Preliminary studies by GWCT showed that there was considerable variation in the spatial pattern of aphid invasion as more aphids occurred within 8 m of the field boundary (Holland et al., 2019). Knowing the likely extent of such spatial variability is important, as this will determine the number of traps needed to obtain an accurate indication of infestation levels per field. To explore this an offset grid of yellow sticky traps (20x20 cm) starting at 5 m from the boundary and spaced at 40 m intervals was deployed across two fields of winter wheat to examine the spatial variability. The field in Hampshire had 72 trapping locations and the Dorset one 54. The field in Hampshire was relatively flat and bordered by tall trees along the northern and south-west boundaries, with a hedgerow along the eastern boundary. The field was almost split by an area of rough grassland (satellite imagery is given in the results). The field in Dorset has a south-easterly aspect, with woodland along the south-east boundary and hedges (2-3 m) around the remainder of the field. Traps were replaced weekly for four weeks and numbers of cereal aphids identified to species and natural enemies to family using binocular microscopes. To identify whether aphids were occurring in patches within the fields and whether there were any significant uninfested areas, data was analysed using Spatial analyses (e.g. SADIE approach) (Winder et al., 2019). The total number of BYDV vector aphids and the natural enemies for each sampling occasion and for the total number collected of each aphid species were analysed. Contour data depicting cereal aphid distributions was generated using the software SURFER.

Table 1. Details of farmer trials using sticky traps. (WW=Winter wheat, WB=Winter barley, WO=Winter oats, MT=minimum tillage, DD=direct drilled, PL=Ploughed)

Farm	Location	No. of fields	Crop	Type of cultivation	No. of times traps deployed	User
1	Dorset	7	4 WW, 3WB	5 MT, 2 PL	2	Farmer
2	Dorset	5	WW	5 MT	4	Farmer
3	Hampshire	4	2 WW, 2WB	2 MT, 2 PL	4	Farmer
4	Wiltshire	4	2 WW, 1 WB, 1WO	2 DD, 2PL	4-5	Agronomist
5	Kent	2	WW	DD	3-5	Agronomist
6	Kent	2	WW	DD	6	Agronomist
7	Kent	2	WW	PL	6	Agronomist
8	Leicestershire	5	WW	2 MT 2 PLvMTvDD trial	4	Farmer
9	Northamptonshire	5	WW	5 MT	2	Agronomist
10	Yorkshire	5	WW	5 DD	4	Agronomist

Optimising sticky trap identification

If many aphids are present on the sticky trap it may be possible to save time assessing them by only counting aphids on part of each trap. To explore the accuracy of this, 110 sticky traps were divided into quarters and the number of cereal aphids counted in each quarter. The estimated number of aphids was then calculated for each trap based upon the number of quarters assessed multiplied by the appropriate figure that then provides an estimate for the area equivalent to a whole sticky trap (4 quarters). This was done for all possible combinations of different quarters when two or three quarters were assessed. Box-and-whisker plots were then generated for when one, two, three or four quarters were assessed per trap.

3.2.3. Assessment of BYDV virus levels within aphids

To test whether sticky traps could be used as a way of collecting aphids for virus testing an associated project was conducted by Lucy Bates (Harper Adams University) for her MSc thesis. The two aims of the project were to: a) ascertain the amount of time for which positive samples remain detectable by the virus assay once exposed on the traps, b) to apply the virus assay to determine the localised nature of aphid infectivity levels.

a) A time-series field experiment was conducted to ascertain the amount of time for which positive samples remain detectable by the virus assay. Using aphids from a colony maintained at Rothamsted Research that are infected with BYDV-PAV, 50 aphids were placed live onto each of 15 20x10 cm 'Wetstick' yellow sticky traps, as used throughout the project, in a 3mm grid pattern to identify them from ingressing aphids. The traps were deployed in a field in Wiltshire during 3-17/12/18 and removed after either 0, 1, 3, 7, 10 or 14 days. Aphids taken directly from the colony for use in the RT-PCR assay were used as a control. Each aphid was tested using a real time RT-PCR Taqman assay for detection of BYDV-PAV in cereal aphids (Williamson, unpublished, 2018) at Rothamsted Research. One-way ANOVA was used to test for the effect of exposure time and virus levels for 0, 1, 3, 7, 10 and 14 days compared between each other using Tukey's HSD test.

b) To determine any variation in localised aphid infectivity levels, aphids were tested using the RT-PCR assay from two field sites that formed part of the study described in 3.3.1. The sites were 2.5 km apart on the same farm and all grain and rose-grain aphids were collected from the traps located at 5 and 70 m from the crop edge and for both two week-long sampling periods. These sites were chosen as they had the highest levels of aphids and provided a total of 407 aphids for virus testing.

3.3. Effect of trap size, boundary type, landscape composition and type of tillage

3.3.1. Effect of trap size, boundary type, landscape composition and type of tillage on immigration of aphid vectors caught on sticky traps

Previous studies showed that both local features (field boundaries, aspect) and wider landscape composition (proportion of arable land, grassland and maize) can influence levels of invading aphids and as a consequence aphid levels differed considerably between and within fields. To investigate this 800-m radius landscape sectors previously mapped and entered into GIS were utilised. Fields were selected in winter sown cereals in the centre of each landscape sector. A total of 24 fields from 15 farms were used. Within each field two transects of four yellow sticky traps located at 5 and 70 m from the crop edge were deployed in each field in the centre of each landscape sector in autumn 2018. Of the four sticky traps, two were 20 x 20 cm and two 20 x 10 cm to test the effect of trap size. Smaller traps may be less prone to blowing away and are cheaper. Traps were deployed for 4 weeks, changing them after 2 weeks. Aphids and natural enemies were counted on the traps by entomologists.

To determine whether the type of tillage was influencing aphid immigration and whether this differed with distance from the field boundary the total number of winged aphids, grain and rose-grain aphids and natural enemies were modelled, using a Poisson distributed GLMM, against the fixed effects cultivation type (a two level factor, plough and minimum till) and trap location (a two level factor, 5 and 70 m). To account for spatial and temporal pseudoreplication present in the data the nested random effects structure Farm/Field/Week was included. Model fit and dispersion were investigated and where overdispersion was present in the data a random intercept was added to the model. Analysis was conducted in R using the package lme4.

To test for the effect of grass coverage in the landscape, GLMMs were built for analysis with insect abundance (total aphids, total natural enemies, grain aphid or bird cherry oat aphid) as the response. The explanatory variable was the three-level factor grassland coverage, low (0-33%), medium (34-66%) and high coverage (67-100%). All models contained the nested random effects structure Farm/Week/Trap distance to account for pseudoreplication present in the data. Overdispersion was evident in 3 models, total aphid abundance, grain aphids and bird cherry oat aphids, and to account for this an observation level random effect was added to the model. All of the crops in this analysis were established using minimum tillage.

To determine how sensitive the two trap sizes were at detecting effects of various factors, two GLMMs, with a negative binomial distribution to account for overdispersion, were built, one for each trap size, investigating relationships between aphid abundance and boundary type, crop type, sampling occasion and distance from the crop edge (5 m or 70 m).

3.3.2. Effect of tillage on aphid immigration and natural enemies in the crop

Levels of aphids and natural enemies in the crop were measured using a Dvac suction sampler on farms in Hampshire (2 ploughed, 2 direct drilled) and Wiltshire (2 ploughed, 2 minimum tillage). Four Dvac samples were taken in the first two weeks of November at 5 and 70 m from the crop edge. Aphids were identified to species and natural enemies to family in each sample. Dvac samples were also taken from the mid-field area (4 samples per field) of 19 fields across two BASF farms in Northamptonshire (5 direct drilled, 6 minimum tillage) and Yorkshire (6 direct drilled, 2 minimum tillage). The data for the sites in Hampshire and Wiltshire was analysed using REML with location of the traps (5 or 70 m) and cultivation type (ploughed or non-inversion tillage) as fixed effects and field nested within farm as the random effect. Logged mean values from the four Dvac samples per sampling location were analysed for grain aphids, bird-cherry-oat aphids, total winged aphids and natural enemies. Sticky trap data for the same sampling period and farms was analysed using the same model. Too few aphids were caught in the majority of the BASF farm fields and therefore the data was not analysed. The number of natural enemies was analysed using REML with cultivation type (direct drilled or minimum tillage) as a fixed effect and field nested within farm as the random effect using logged data.

3.4. Developing key messages for farmers to improve their knowledge and approach to BYDV management

The study was promoted through a variety of traditional printed and modern media, events with land managers, collaborative trials/surveys with farmers and agronomists. Feedback was sought from farmers and agronomists through the online survey and interviews with farmers participating in the field studies.

4. Results

4.1. Review of decision tools for BYDV

4.1.1. Literature review

The searches performed on Web of Science & FAO Agris yielded respectively 23 and 12 papers on decision support tools and 31 and 86 papers on management practices. Records listed by Agris included several duplicated entries and numerous papers in languages other than English. There was a complete overlapping between the two bibliographic sources for papers considered suitable to be included in the review.

Decision Support Tools

Based on the information present in the abstract, a total 46 papers and 10 AHDB reports were selected for review. A further 10 papers were selected from the bibliographic section of the reviewed papers and from Mendeley alerts.

A total of 11 models/decision support tools (entries) were fully reviewed (see Appendix I). Often more than one paper referred to the same system, e.g., progressive developments over the years. In this case only the most recent and comprehensive paper was included. For simplicity, the entries are referred to by means of an identification code "M0- -" followed by a progressive number from 1 to 11. The correspondence between the identification code and the bibliographic reference is reported in Appendix I.

For the entries to be considered suitable to future projects, a few characteristics were evaluated in relation to the input, output and readiness to application (market). Based on the preliminary results of this project, attention was focused on those models that used input information from either suction trap or traps in a local field. The amount and complexity of inputs (difficulty in retrieval) were also considered.

In terms of output, ideally a tool should provide information on the likelihood of onset and severity of BYDV, the latter potentially expressed as crop loss. Another important factor considered was whether the entry described a system either to be immediately tested or with potential to be applicable to the UK, but in need of further investigation prior to application.

Five entries were deemed not suitable for future projects, the reasons were: not applicable to UK conditions (M002 is specific for Mediterranean conditions), elevated complexity of input and adaptation to local reality needed (M001), and no relevance to the project (M003 and M010 simulates the number of immigrating individuals, and M006 simulates dynamics of serotypes in secondary spread of the virus).

All the entries deemed "suitable" need further research/work to make the tools ready for use.

Three entries (M004, M009 and M011) described models built on empirical approaches, such as regression analysis, in countries other than the UK (New Zealand and France). More extensive work and research will be expected to evaluate these works as they would not be suitable for direct testing in the UK. The risk with empirical models is that they may potentially not perform well under conditions different from those in which they were developed. Nevertheless, the methods described could be replicated resulting in either the calibration of the existing models or the development of altogether new models.

M004 was developed in New Zealand and simulates the abundance of aphids during the season by using different environmental variables and aphids catches from the previous year. The decisions supported are therefore strategic ones, such as the use of seed dressing (no longer relevant to the UK) and sowing date. Both M009 and M011 were developed in France and support tactical decisions around the spray necessity and timing. Specifically, M009 estimates the potential proportion of plants infected by BYDV, by using temperature or aphid information (suction trap data or number of infested plants) as inputs, whilst M011 estimates the potential crop losses caused by BYDV by using the proportion of plants infested by aphids as an input.

The remaining three entries (M005, M007 and M008), although being already specific to the UK or being built on approaches which will allow direct implementation into this country, will need further work either to translate the outputs into information relevant for decision making (M005) or to further test the validity of risk criteria and accuracy levels (M007) or to bring the system at field level (M008).

M005 describes a stochastic population dynamics model, which requires as input the current daily and the 20-year average temperature and the assessment (once per season) of the proportion of plants infested by aphids. As output, it returns the probability distribution of the area under the curve of the percentage of plants infested during the autumn, supporting decisions around the need and timing for an insecticide application. The model was developed in France and exclusively focuses on bird cherry-oat aphid (*Rhopalosiphum padi* population). The risk of BYDV onset and spread is not considered. Record M005 can be used in connection with M011 (authored by the same group of researches of M005), which estimates crop losses and in order to be of practical use has to be completed by a predictive model of population dynamics of bird cherry-oat aphid in autumn (namely M005). This record and M011 were the basis of aphi.net decision tool deployed by INRA and Bayer in France, but which is no longer available.

M007 describes the decision support tool (DST) for aphid management in winter cereals embedded in DESSAC (Decision Support System for Arable Crops), an integrated suite of DST modules covering the main decision areas confronting arable farmers developed in the 1990s in the UK and funded by different bodies. Several publications (peer reviewed articles, conferences papers, and project reports) have been produced to document and disseminate the work which led to the development of M007. In the current review, information is mainly derived from the HGCA Project Report 205 (Development and validation of decision support methodology for control of barley yellow dwarf virus) and the Final Report of the MAFF-funded project AR0308 (Evaluation of research into BYDV epidemiology and optimisation of its application on commercial farms).

The DST is based on a weather-driven (daily temperature) stochastic simulation model of secondary spread, initialized on the basis of aphid captures in suction traps (both bird cherry-oat aphid and grain aphid (*Sitobion avenae*) are considered). This provides a regional risk estimate, which is made field specific based on relationships between virus incidence and field characteristics (crop type, drilling date, distance from the sea, and whether the surrounding area is mainly arable). The final output is one of five risk categories. Each of these categories is based on the economics of control and the category thresholds differ between the two crop types (wheat and barley) due to differences in their yield and grain prices. These economic thresholds can be used to decide the necessity and timing for an insecticide application.

The stochastic simulation model is a derivation of previous works (Morgan, 2000; Morgan & Morse, 1996 - not included in this review) and was constructed under MAFF-funded project CE0410, for which no report was found. The model was validated over a dataset of 5 cases, covering three sites in the UK and two years. Its accuracy was deemed encouraging by the authors of the HGCA Project Report 205, who also identified two potential shortcomings in the assumption that no "green bridge" infection occurring and in the need of better quantifying the winter aphid mortality.

The model was programmed in JavaScript and the DST was made accessible via a web-application at http://www.csl.gov.uk/bydv, but this no longer exists.

M007 is the only model/decision support included in this review which took into consideration field-specific characteristics.

M008 describes a mechanistic model, which simulates the spread of BYDV, both primary and secondary, caused by bird cherry-oat and grain aphids. The model returns as output the proportion of plants infected by BYDV by using as inputs the daily values of temperature and aphid information, such as the number of catches from the suction trap and the proportion of infected migrant aphids. The authors suggested that the present model could be used as the basis of a decision support around the necessity and timing for an insecticide application, provided that yield losses can be estimated from the proportion of infected plants. The model was developed and tested in the South West of England, covering 11 years of data collected from 61 cereal crops. Although these data came from one location, they covered a wide range of agronomic and climatic conditions which resulted in very variable field infections ranging from 0 to 80% of the crop area. The model was originally programmed in VAX BASIC version 3.0.

The three entries (M004, M009 and M011), based on empirical approaches and which will need work to replicate the studies before being suitable for application into the UK, all relate to bird cherry-oat aphid. This species is also the most abundant in the suction traps samples across the UK, however in the present project the most recurrent species was the grain aphid. M005 also refers to bird cherry-oat aphid only. These four entries were therefore excluded from our recommendation for future works.

Management Practices

A total of five papers were deemed suitable for inclusion in this review. As with the work on decision support, the entries are referred to by means of an identification code: "P00 -" followed by a progressive number from 1 to 5. The correspondence between the identification code and the bibliographic reference is reported in Annex I.

P001 reports on a study investigating the landscape influence on the intensity of wheat colonization by bird cherry-oat aphid in the autumn in France. Maize and grasslands were compared as source of migrants, showing that colonization was increased by the presence of maize, but reduced by the presence of grasslands within a 1000 m radius.

P002 refers to two studies carried out in Ireland by the same group of authors and published in 2010 and 2012. These works assessed aphid abundancy on untreated crops of barley and wheat during the autumn under two different tillage methods: minimum and conventional. In general, there were fewer aphids and a significantly lower incidence of BYDV in the minimum tillage than in the conventional tillage crops. The difference in aphid number was attributed to the immigration of winged aphids, which in turn was attributed to the differences in the visual cues between the two crops. In the conventional tillage system, the green foliage of the crop contrasts well against the darker soil background offering clearer cues for landing than the stubble trash associated with minimum tillage. In both these works a positive relationship between aphid abundance on crops in autumn and the subsequently prevalence of BYDV was observed.

P003 refers to a study carried out in France where the viruliferous status of migrant winged bird cherry-oat aphid caught in suction traps was tested using a TAS-ELISA technique. The proportion of migrant winged aphids that carry viruses in autumn was considered a major epidemiological factor for determining the disease incidence. The authors investigated the relationship between this proportion and the weather conditions and land use. The fluctuations of the proportion of viruliferous aphids were found to match the variations in: i) the annual day-degree accumulation above 5°C during the first 8 months of the year, and ii) the ratio of land sown to small grain cereals (wheat, barley and oats) compared to that sown to maize. The latter finding is possibly explained by the fact that small grain volunteers can potentially reach a higher proportion of infected plants than maize, thus being a better source of the virus.

P004 reports on the wide survey conducted in the UK on untreated autumn-sown cereal crops (mainly wheat and barley) to evaluate the influence of fields characteristics on BYDV incidence. Among the crop and field characteristics considered there were: sowing date, regions as defined by their geographical position, topography and climate, the proximity of the field to the sea, the extent of arable land in the vicinity of the field, and the aspect and size of the field. The proximity of the field to the sea and the non-prevalence of arable land in the surrounding area were embedded as risk factors in M007.

P005 refers to a study carried out in the UK where the effect on BYDV incidence of crop residue management and cultivation techniques were investigated. Results showed that virus infection was more prevalent after ploughing than after non- inversion tillage or direct drilling. Straw baling generally led to more infection than straw incorporation. The numbers of predators in autumn showed the opposite trend of prevalence of that of subsequent virus infection (direct drilled > non-inversion > ploughed).

Several other papers not relevant to the scope of this review, showed how a later sowing date is generally associated with a lower number of immigrating aphids and the subsequent onset of BYDV.

4.1.2. Survey of farmers and agronomists

The full questionnaire and replies are reported in Appendix II. A total of 182 respondents took part in the survey. Of these 72 were farmers/farm managers (40%) and 110 were agronomists (60%). Below overall results are provided for the two separate sections of the questionnaire.

Results for section on current practice

The majority of the respondents (>85%) were from the central and southern regions of the country. Farm sizes ranged from <50ha (6%) to >750ha (7%) with the 60% of 50-250 ha and 27% of 250-750 ha.

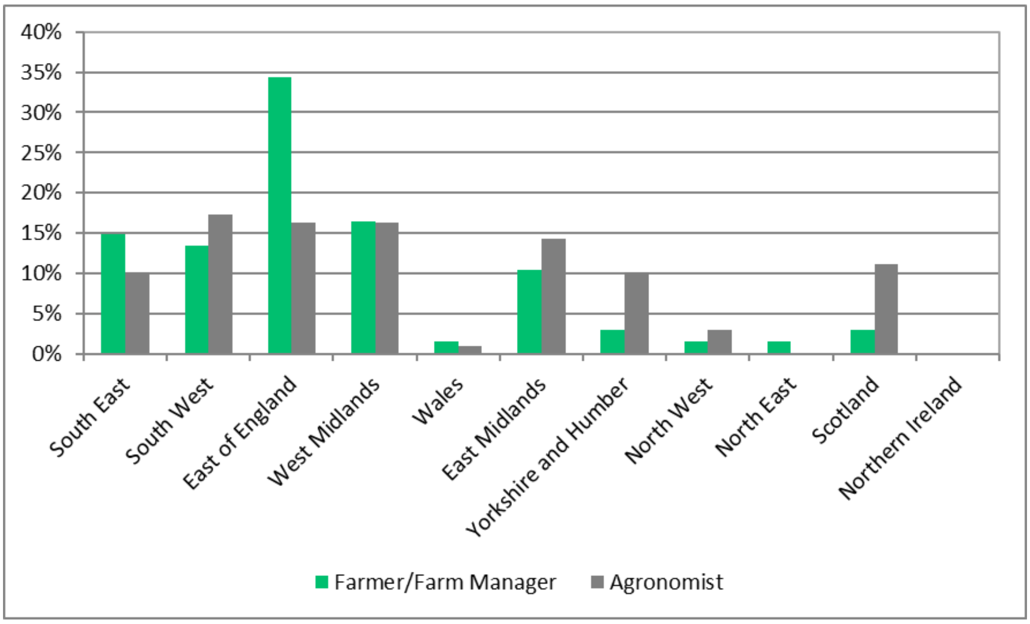


Figure 1. Location of respondents for farmers and agronomists.

To understand how aware the respondents are to the threat of BYDV, they were asked when they last saw symptoms in their crop, given a choice between pre-introduction of neonicotinoid seed dressing and a detailed year by year list for the period post introduction. More farmers/farm managers replied “never” than agronomists (9 versus 2%), which makes sense given the number and variety of fields scouted by an agronomist compared to a farmer/farm manager. Specific single years during the 90s and 2000s were mainly indicated by farmers, with the most recurrent one being 2002 (5% of farmer/farm manager) (Figure 2). The majority of the years was identified from 2012 onwards, with the highest frequency for the last 2 years, 2016 chosen by about 18% of the respondents and 2017 chosen by 18% of farmer/farm manager and 49% of the agronomists. This can be ascribed to the higher number and variety of fields scouted by agronomists.

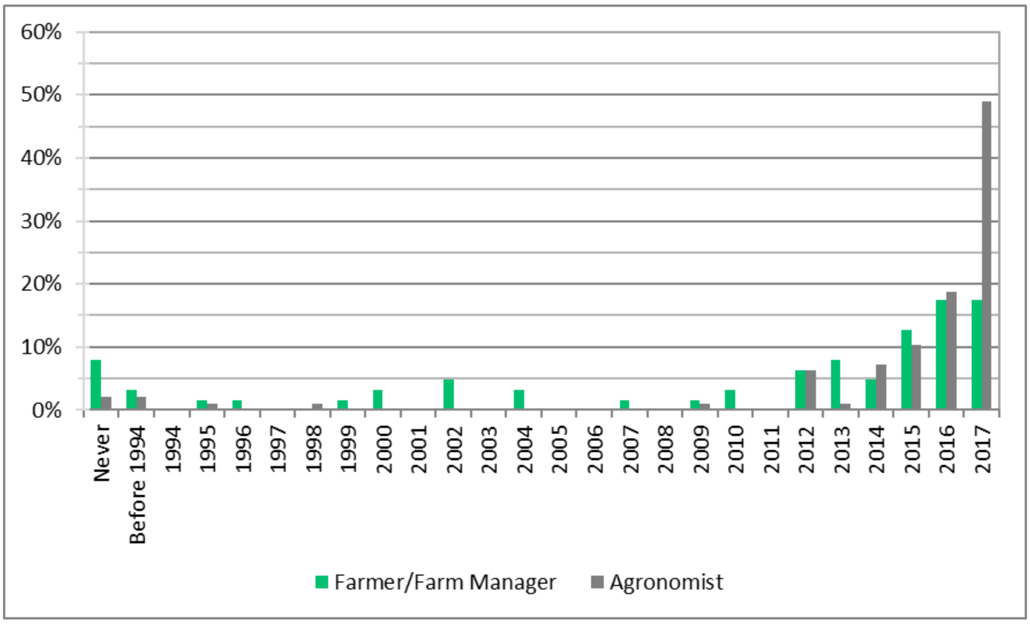


Figure 2. Years that farmers and agronomists observed symptoms of BYDV.

The most frequent answer of the likely cause for BYDV to develop in those years was the lack of insecticide protection (*c* 45%, Figure 3). The second most frequent reason was the inability to enter the field on time due to adverse weather conditions (24-33%) which would also result in no insecticide protection. About the 11% of farmers/farm managers and 8% of agronomists blamed the inadequate forecasting of aphid risk. A small proportion of respondents indicated among other causes the use of seed dressing only, which was not followed by foliar insecticide applications when the protection ran out.

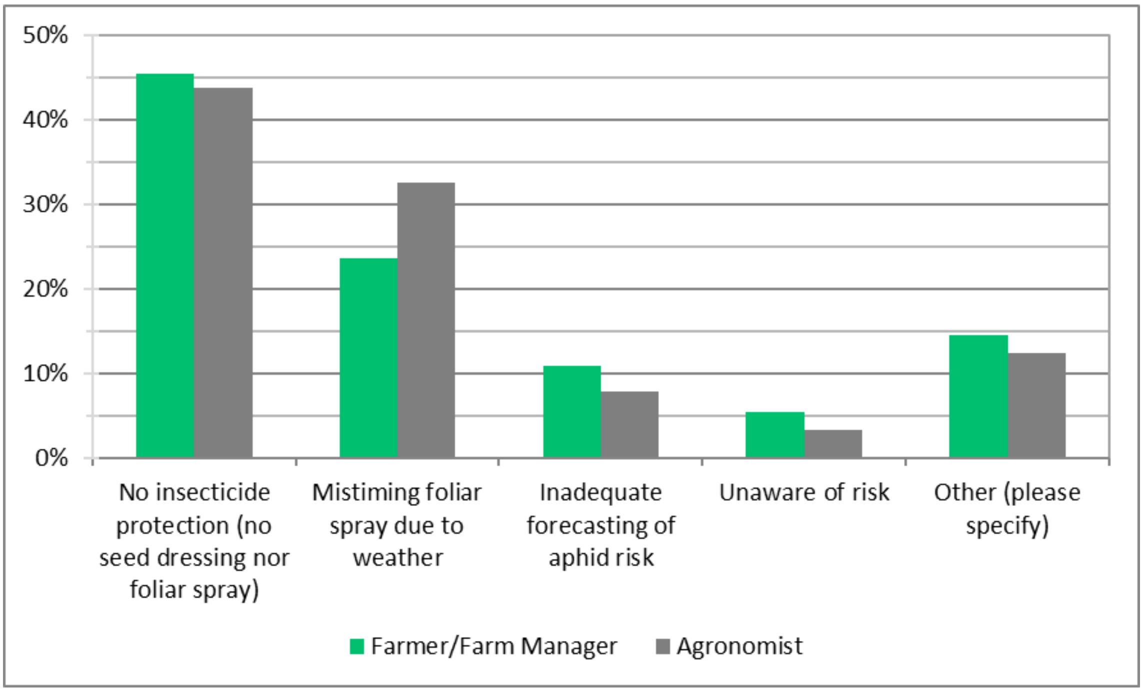


Figure 3. Likely cause for BYDV to develop.

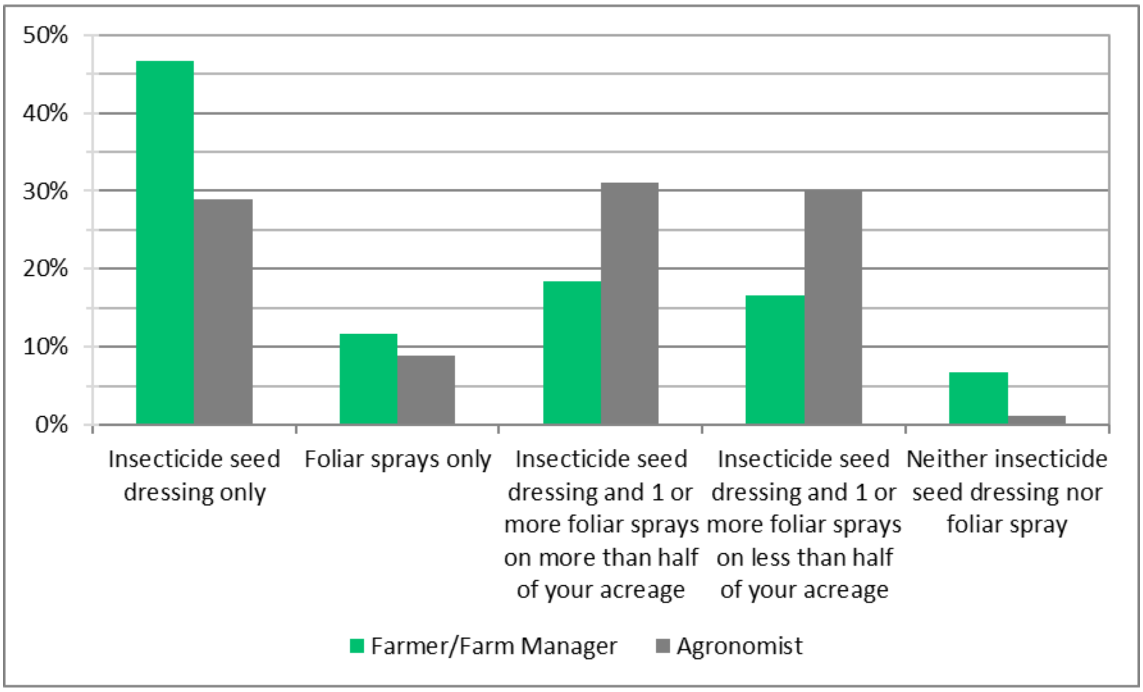


Figure 4. Most common approach for aphid control and BYDV management in the last 5 years.

47% of farmers and 29% of agronomists reported that the use of insecticide dressed seed with no follow up foliar application was the most common approach for aphid control and BYDV management adopted in the last 5 years (Figure 4). About 35% of farmers and 61% agronomists reported to use both insecticide coated seed and foliar insecticide (in about equal proportion between following this approach on majority of their acreage or on less than half). This mixed approach was most prevalent (35%) in medium size farms (50-250 ha), whilst the reliance on seed dressing only was observed as the most prevalent approach in all the other farms size categories.

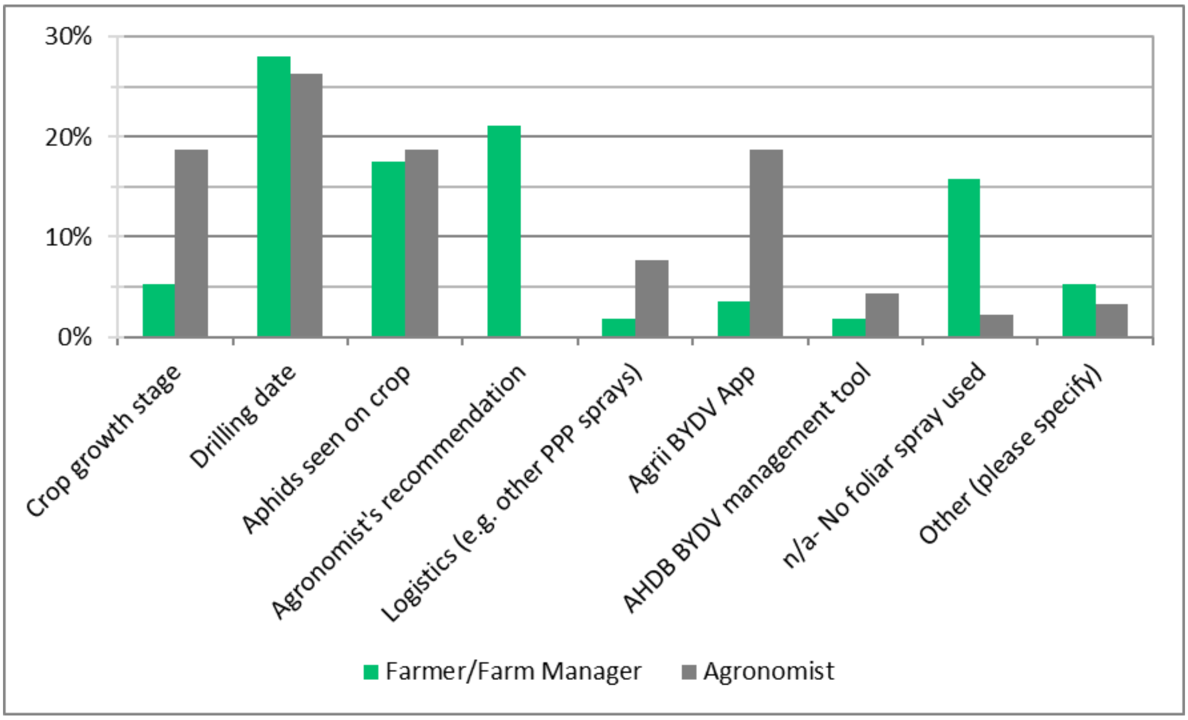


Figure 5. Factors triggering the first foliar insecticide application when no seed dressing was used.

The farmer/farm managers who did not use treated seed, but applied foliar sprays, based their decision on when to treat mainly on drilling date (28%) and aphids seen on crops (18%) (Figure 5). About 20% rely on their agronomist's recommendation, who in turn based their decision most often on drilling date (26%), and then in equal measure (19%) on the phenological stage of the crop, the presence of aphids in the crop, and a T-sum calculator, such as the BYDV App by Agrii. Respondents who chose the option "Other" did not provide any actual other options, but reiterated those options provided in the question or a combination of them. One agronomist indicated the use of the data from the Rothamsted Insect Survey.

Over 90% of both farmers/farm managers and agronomists declared they practiced IPM.

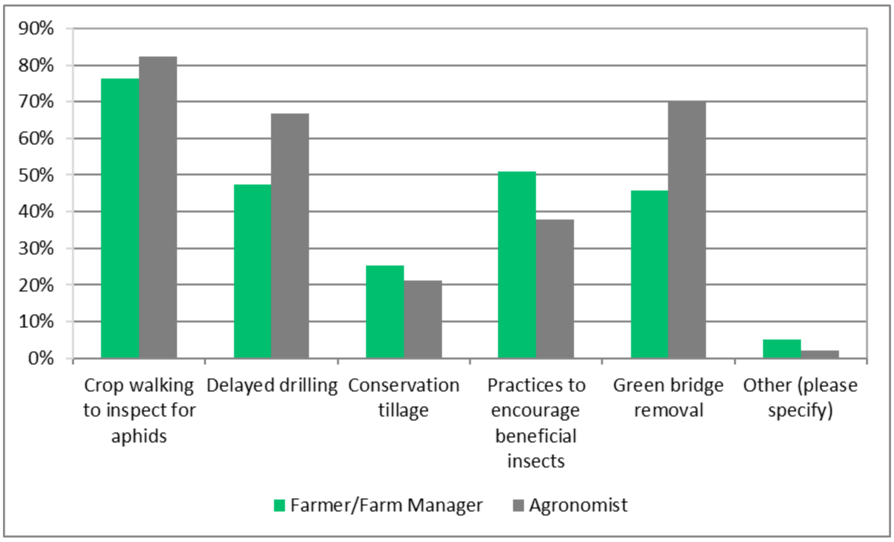


Figure 6. IPM strategies for aphid control and BYDV management.

Among the IPM practices already adopted (Figure 6), crop walking to inspect for aphids was the most common IPM approach adopted by all respondents (>75%). Agronomists also indicated in high percentage the delay of drilling and the removal of green bridges. Practices to encourage beneficial insects were also chosen with moderate frequency (51% farmer/farm mangers and 38% agronomists). Conservation tillage was the least selected. “Other” options provided by farmers/farm managers included the use of crops and varieties more tolerant to BYDV, whilst the agronomists included the use of a T-sum calculator.

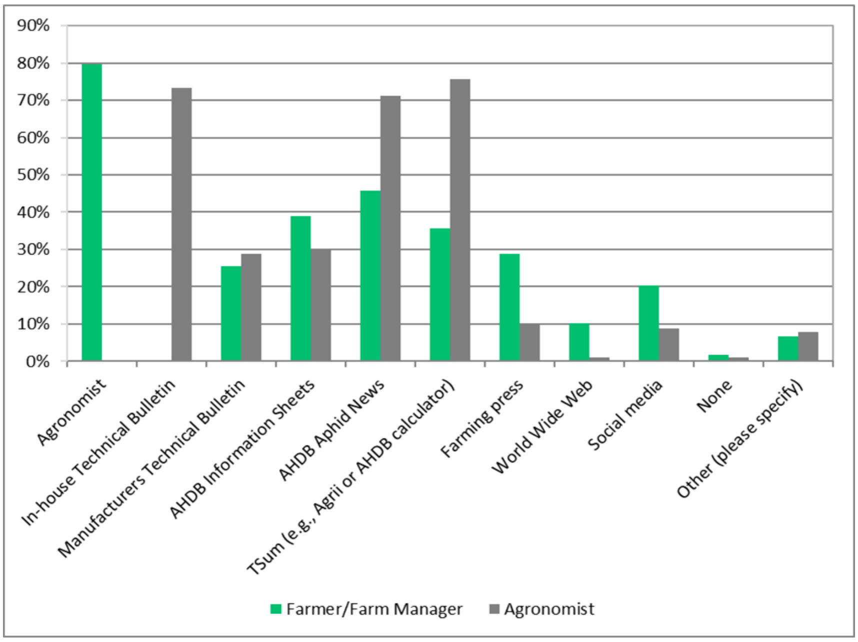


Figure 7. Sources of information to support decisions around aphid control and BYDV management.

The most common sources of information to support decisions around aphid control and BYDV management (Figure 7) were the agronomists for farmer/farm managers (80%), followed by the T-Sum calculator, the AHDB Aphid News and the AHDB Information Sheet (all ≥30%). For agronomists the most common sources (all reported by ≥70% of respondents) were the T-Sum calculator, in-house technical bulletins, and the AHDB Aphid News.

Detailed results – section on decision support

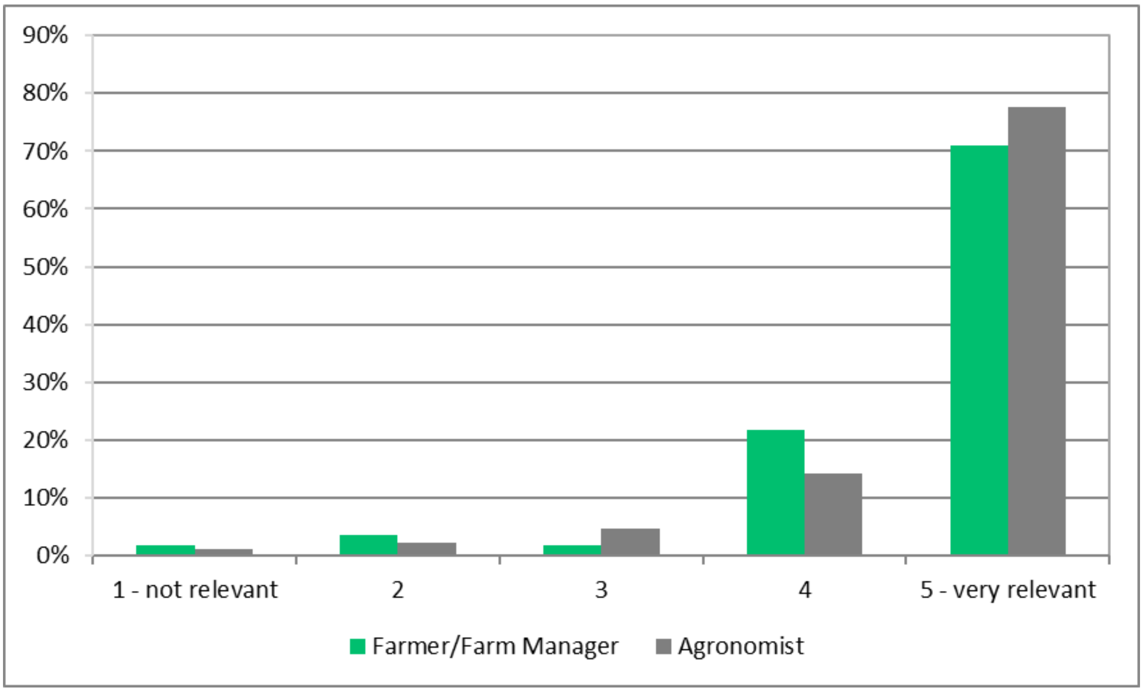


Figure 8. Need of further support/information for aphid control and BYDV management following the ban of neonicotinoid seed dressings.

92% of both farmers/farm managers and agronomists deemed relevant/very relevant additional information for aphid control and BYDV management following the ban of neonicotinoid seed dressings (Figure 8).

The most popular factor to be considered for supporting decision on the need and timing of insecticide applications was an aphid threshold for farmers (selected by 93% of the respondents) and the T-based threshold for agronomists (88%) (Figure 9). Agronomists also selected with high frequency (>75%) the aphid threshold and the insecticide resistance status, almost two third of them also selected field risk specific factors. Other popular factors

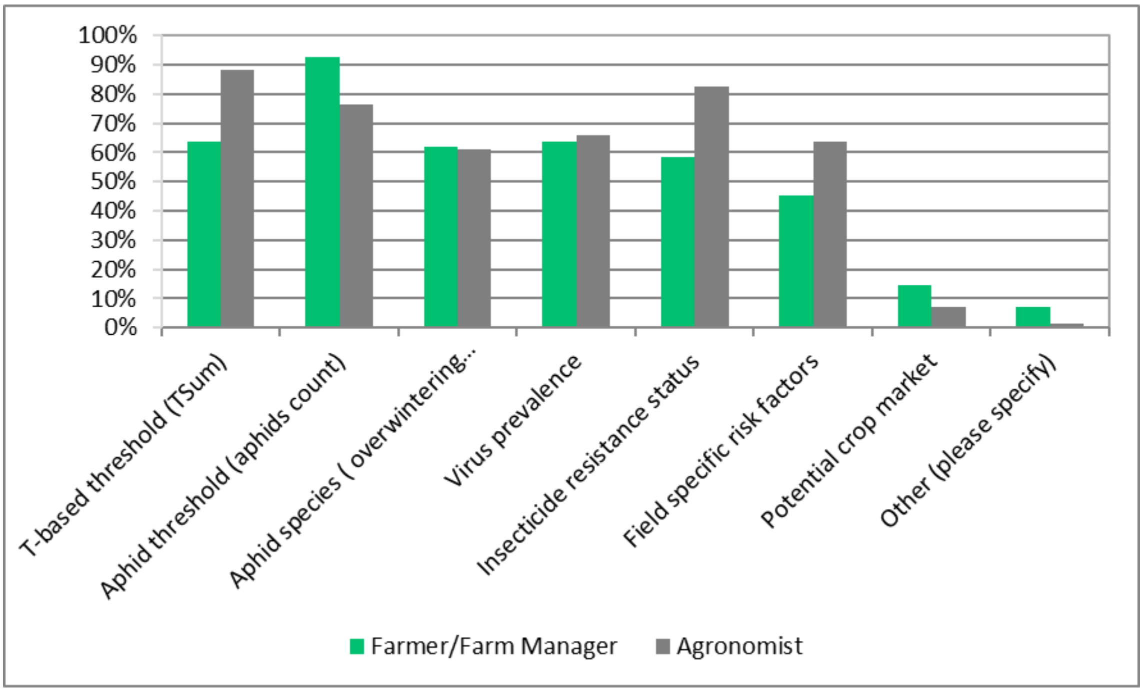


Figure 9. Factors to be considered for supporting decisions around the need and timing of insecticide applications.

(>60%) among both respondents were aphid species and virus prevalence. The least frequent factor selected by both type of respondents was the potential crop market (≤15%). Among “other” options, two farmers/farm managers reported the need to raise awareness of beneficial insects and spiders, and the assessment of their presence prior spraying.

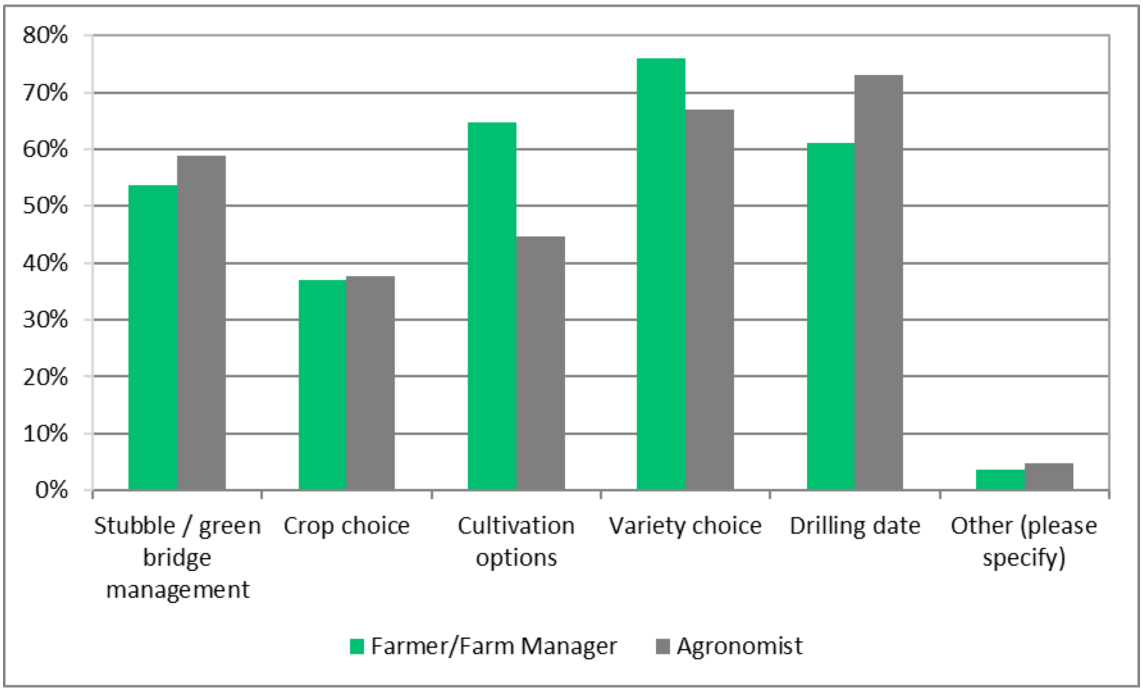


Figure 10. Support needed on crop management actions impacting on the risk of BYDV spreading.

When asked for which crop management actions respondents would like to receive guidance via a decision support tool for aphid control and BYDV management, drilling date and variety choice were the most popular options (>60%) (Figure 10). Farmers also frequently selected cultivation options (65%). More than half of both types of respondents also indicated stubble / green bridge management. Crop choice was the least popular (37-38%).
Under "other" options, one agronomist listed cover crops and their possible role in enhancing the risk for BYDV.

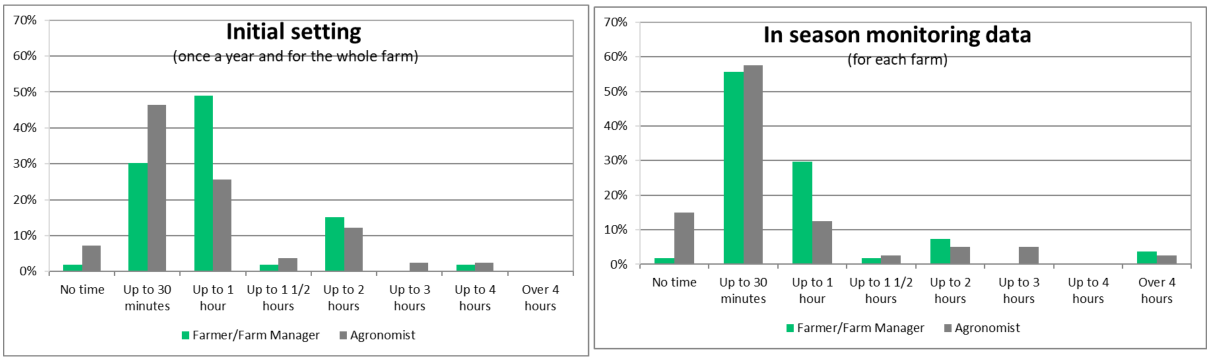


Figure 11. Willingness to commit time to use a decision support tool.

The majority of respondents (≥70%) of both types expressed the willingness to dedicate between half an hour to an hour to input information into a decision support tool (Figure 11). Agronomists indicated with greater frequency up to half an hour, whilst farmer/farm manager's most popular choice was up to an hour.

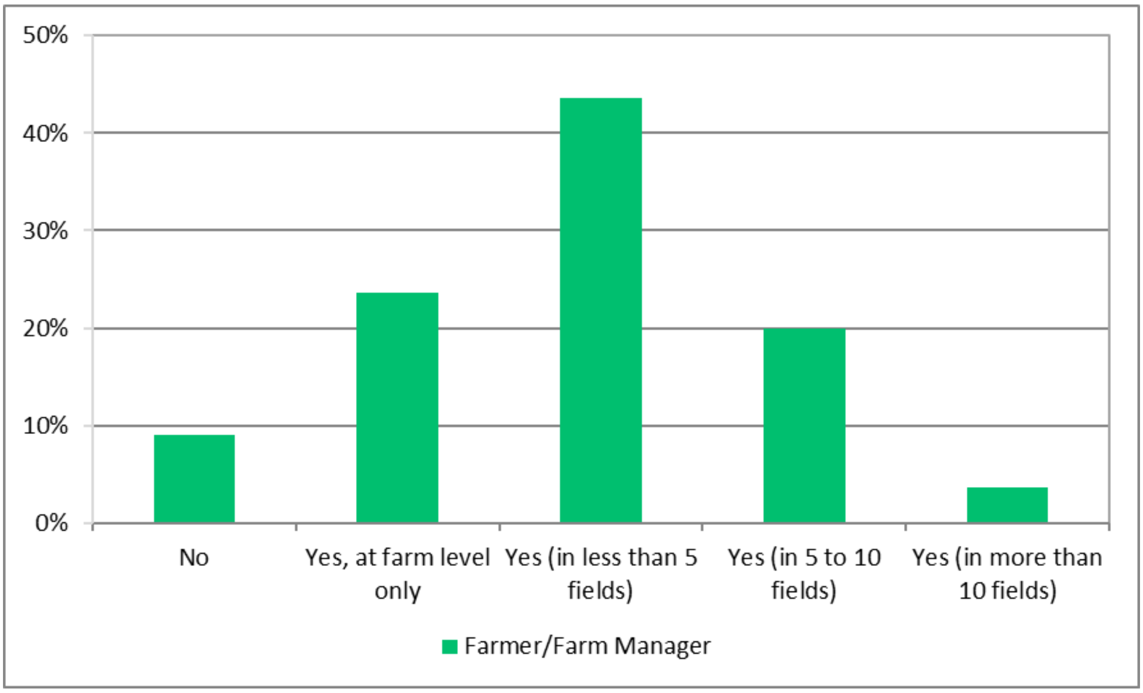


Figure 12. Willingness to monitor aphids by means of sticky traps.

Farmers/ Farm managers were asked if they were willing to assess in-crop sticky traps on a weekly basis in order to determine treatment timing. The majority (44%) expressed willingness to check traps on up to 5 fields (Figure 12).

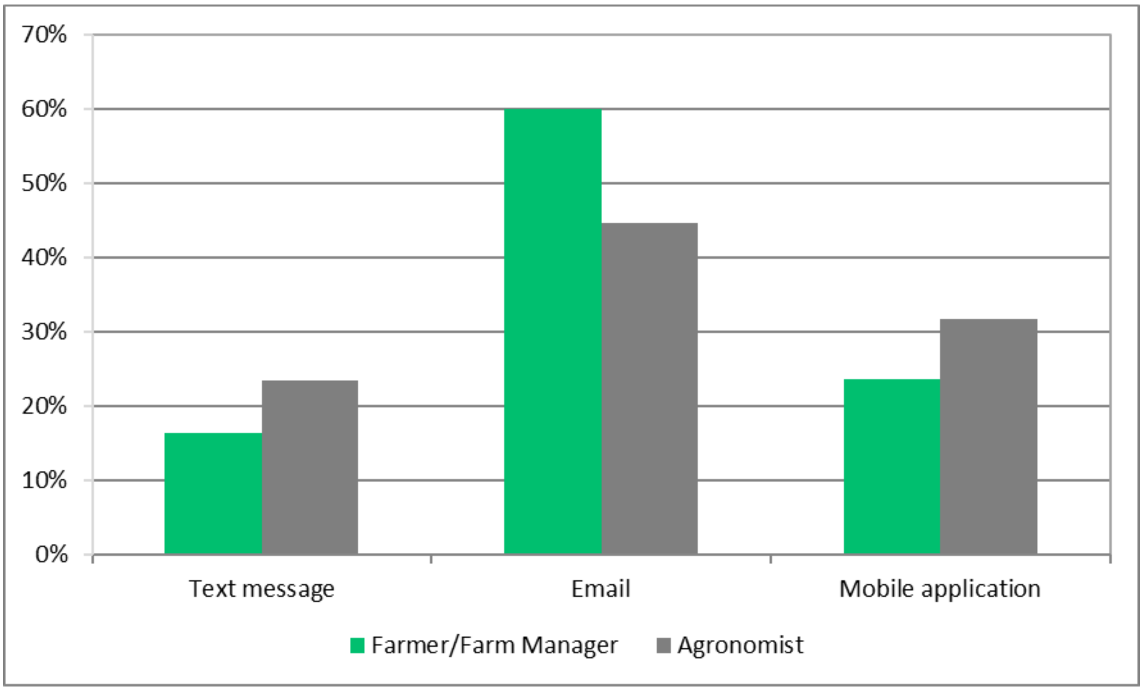


Figure 13. Delivery method of information about aphid/BYDV risk from a decision support tool.

The preferred way to get information about aphid/BYDV risk from a decision support tool was email for both type of respondents (60% of farmer/farm manager and 45% of agronomists) (Figure 13). A mobile App was the preferred option for 32% and 24% of the agronomists and farmer/farm manager respectively.

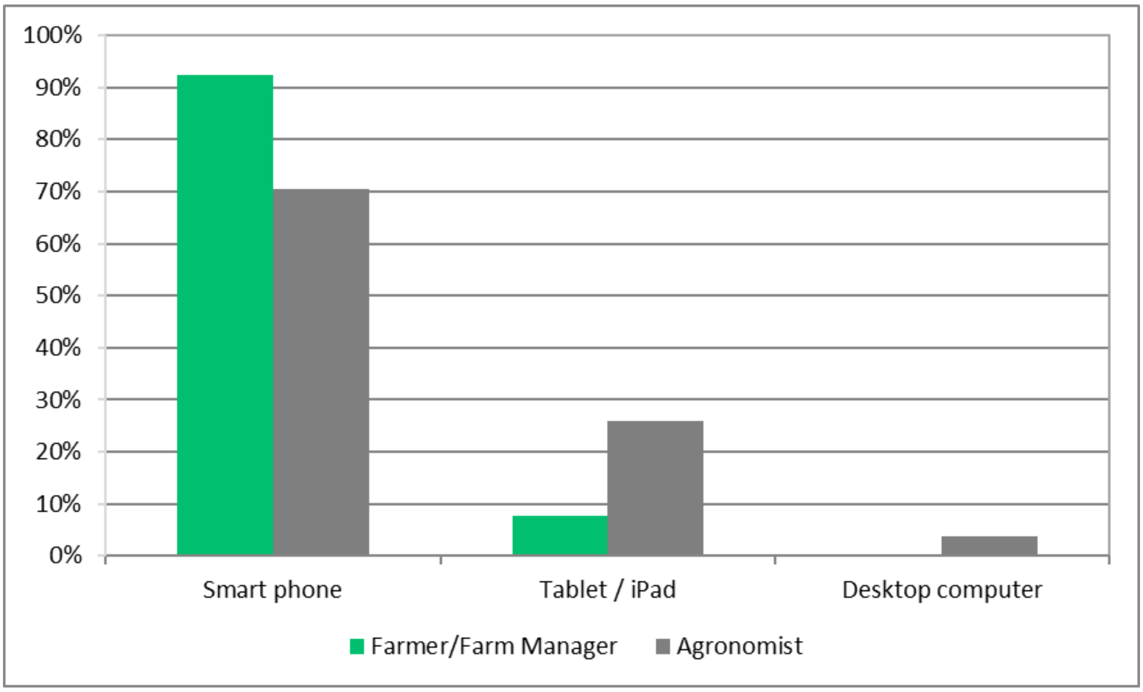


Figure 14. Preferred device through which to access the decision support tool.

Those who opted for the mobile app indicated the smart phone as the preferred device to access the decision support tool (Figure 14).

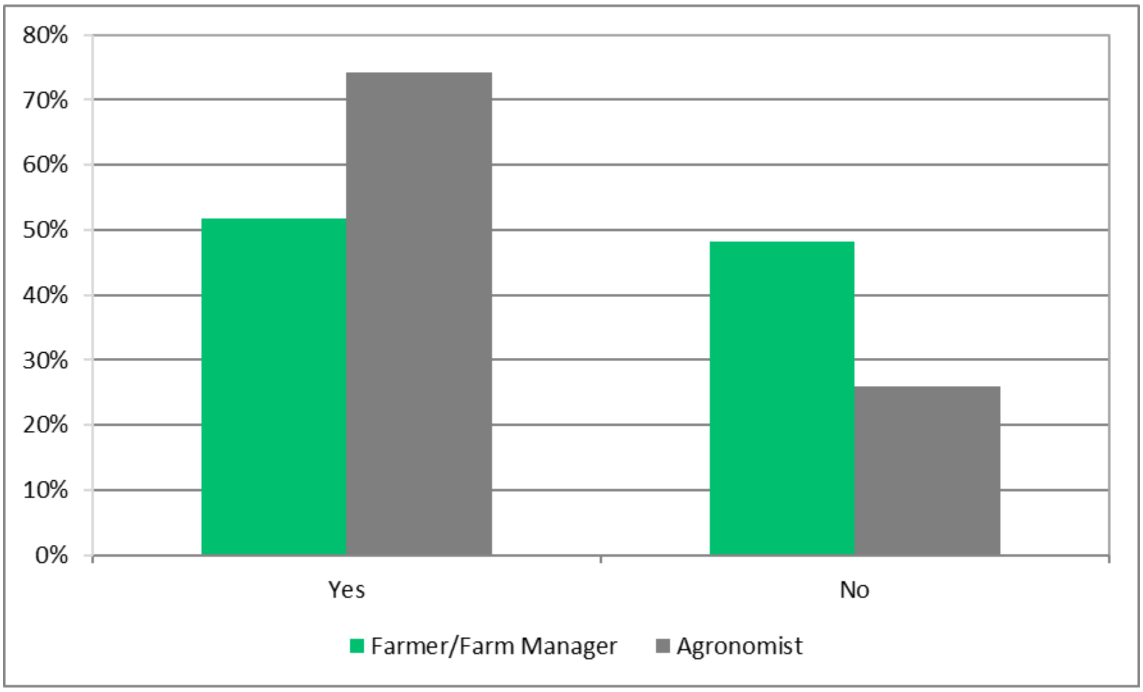


Figure 15. Experience of using monitoring systems or other decision support tools to help the selection and timing of crop protection actions.

About 74% of the agronomists replied to have already been using decision support tools against 52% of the farmer/farm manager (Figure 15).

Below the tools used by the respondents are listed in a decreasing order of frequency:
OWBM

Other sticky, pheromone & water traps

BYDV App

Pollen beetle predictor

AHDB Aphid News

BruchidCast

4.2. Evaluation of field-specific monitoring methodology of aphid vectors of BYDV

4.2.1. Predictive capability of aphid monitoring

The level of BYDV was significantly higher ($F_{1,6}$=39.9, P<0.001, for Asin transformed data) in the untreated plots (no foliar insecticide) (Table 2). Yields were significantly lower ($F_{1,6}$=8, P<0.05), in the untreated plots as was the crops Specific Weight ($F_{1,6}$=11.9, P<0.05).

Table 2. Yield, specific weight and level of BYDV in the plots treated with a foliar insecticide and untreated plots.

	Yield t/ha @15% m.c.	Specific Weight (kg/hl)	% BYDV
Treated	9.44 ±0.12	65.34 ±0.22	0.31 ±0.73
Untreated	8.93 ±0.13	64.34 ±0.23	2.68 ±0.55

The most abundant aphid species found on the crop was bird cherry-oat aphids (70%), whilst grain aphids comprised 24% and rose-grain aphids 6%. Very similar proportions were found on the sticky traps with bird cherry-oat aphids comprising 63%, with the remainder being grain aphids (30%) and rose-grain aphids (7%). Most aphids invaded the crops during week 2 (Fig. 16)

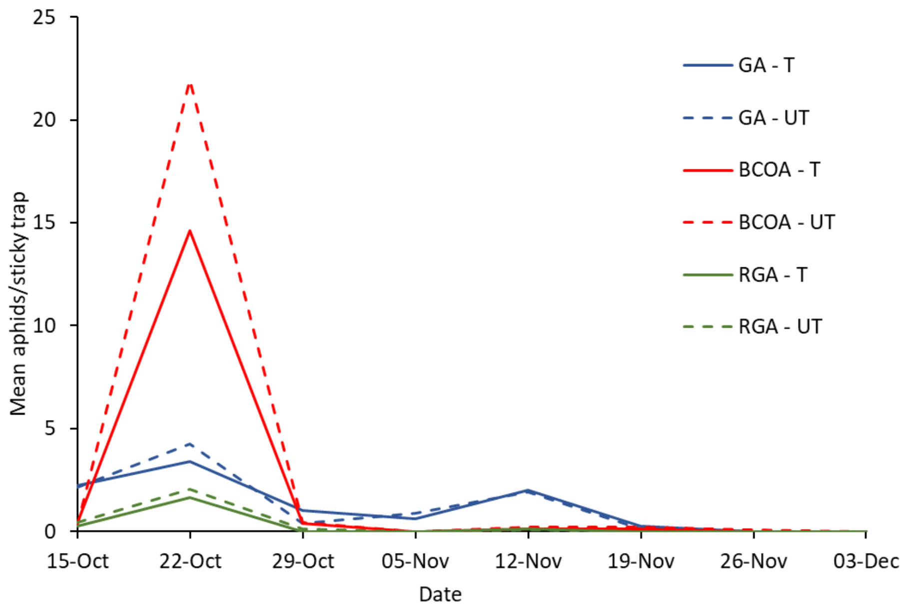


Figure 16. Mean number of aphids per sticky trap in the treated (T) and untreated (UT) plots for the three aphid species (GA=grain aphid; BCOA=bird cherry-oat aphid, RGA=rose-grain aphid) at weekly intervals over the autumn (8/10-3/12/18).

There were no significant differences between treated and untreated plots in the total numbers of aphids observed on the plants or on the sticky traps, nor for any of the three aphid species recorded on the sticky traps (Table 3). Numbers of aphids were, however, much lower on the plants in the insecticide treated plots (Fig. 17). Natural enemies declined over the sampling period, matching the trend for aphids.

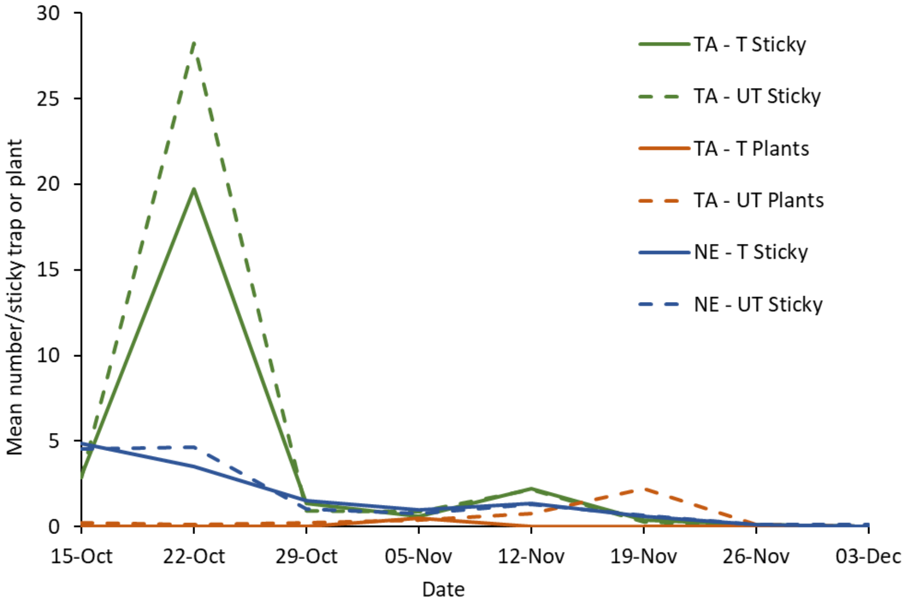
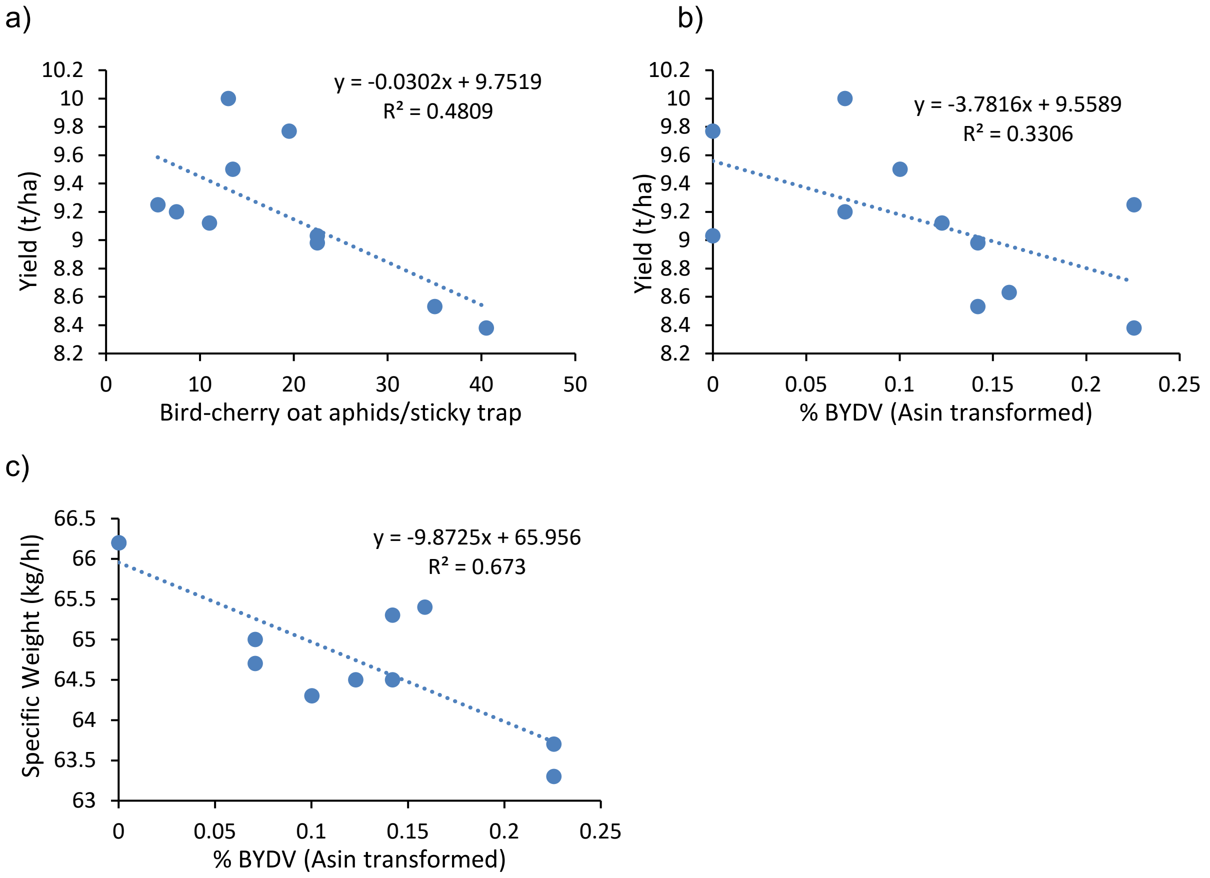


Figure 17. Mean total number of aphids and natural enemies per sticky trap and mean number on the plants in the treated (T) and untreated (UT) plots at weekly intervals over the autumn (8/10-3/12/18).

Table 3. Total aphids on the sticky traps for the plots treated with a foliar insecticide and untreated plots.

	Grain aphids	Rose-grain	Bird cherry oat	Total
Treated	9.5 ±1.0	2.0 ±0.5	15.6 ±3.1	27.5 ±3.4
Untreated	9.7 ±0.7	2.7 ±0.3	23.1 ±2.2	35.5 ±2.4

The linear regressions revealed that the number of bird cherry-oat aphids captured on the sticky traps was negatively related to the yield ($P<0.01$, $R^2= 0.48$, Fig. 18a) and that the % BYDV was almost significantly related to yield ($P=0.06$, $R^2=0.33$, Fig. 18b) and Specific Weight ($P=0.06$, $R^2=0.67$, Fig. 18c). This aphid species was the most abundant one caught on the sticky traps, but was not correlated with levels of BYDV. It is possible that aphid immigration occurred from the nearby whole-crop forage barley and not by aerial migration.



Figures 18a–c. Relationships between yield and numbers of bird cherry-oat aphids on sticky traps (a) and % BYDV (b), and effect of % BYDV on Specific Weight (c).

4.2.2. Reliability and practicalities of the sticky trap approach

Farm trials using unsprayed plots

In the trials in Kent 68% of BYDV vector aphids caught on the sticky traps were grain aphids and 31% bird cherry-oat aphids, whilst rose-grain aphids comprised only 0.6%. The majority of grain aphids were captured during one week in early November whilst bird cherry-oat aphids were caught in late October to early November (Fig. 19). Natural enemies were active throughout the sampling period with a small peak in late November. They were comprised of parasitic wasps (85%) and money spiders (Linyphiidae) (15%).

Only 13 BYDV vector aphids were observed on the plants across the whole trial even though the sticky traps were showing that aphids were flying into the fields. The weather during the study was wet and this may have reduced aphid survival, whilst wet conditions also made it difficult to observe the aphids on the crop.

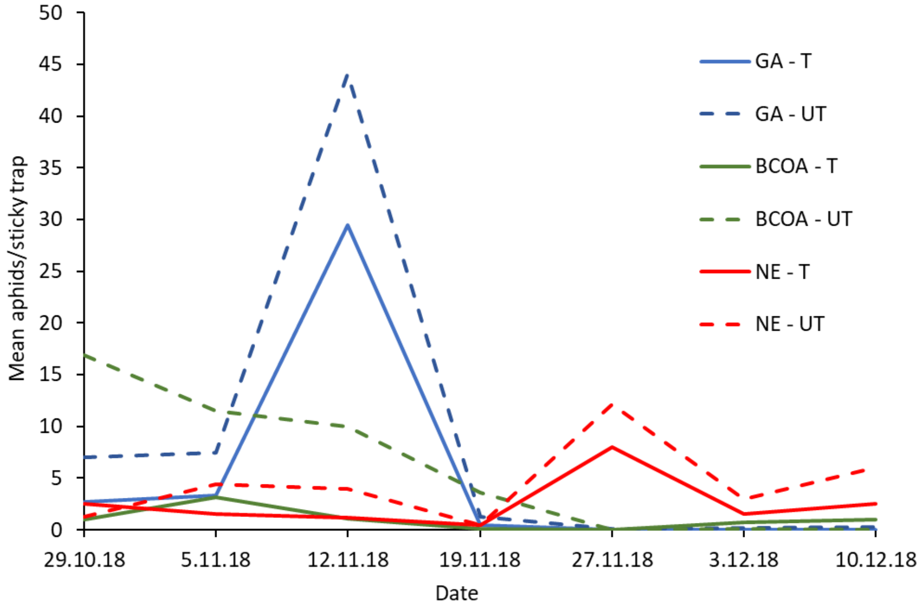


Figure 19. Mean number of aphids per sticky trap in the treated (T) and untreated (UT) areas in six fields in Kent for the three aphid species (GA=grain aphid; BCOA=bird cherry oat aphid, RGA=rose-grain aphid) for at weekly intervals over the autumn (29/10-10/12/18).

There was no significant difference in the total numbers of each the three aphid species or the total number of aphid BYDV vectors between the treated and untreated areas.

In the trial in Wiltshire, no aphids were found on the plants and there was no sign of BYDV infected plants in the spring, therefore the data was not analysed to compare treated and untreated areas.

Farmer trials of sticky traps

A total of 396 sticky traps were deployed catching 2,861 (62%) grain aphids, 1,642 (36%) bird cherry-oat aphids and 75 (2%) rose-grain aphids. For 10 farms, the number of aphids on the sticky traps was assessed by seven farmers or agronomists (3 farms were assessed by one agronomist) by eye, using a magnifying glass or a binocular microscope. Sticky traps were then inspected under a binocular microscope by a GWCT expert to determine the accuracy of the original assessments. This revealed that five of the farmers/agronomists underestimated the number of aphids by 50-89%, whilst two overestimated their numbers by 80-82% (Fig. 20). Despite this, Spearman's Rank correlation test showed that for all but one of the non-experts there was a significant correlation between the values for the two assessors, indicating that the system could at least be used for determining changes over time.

The six farmers and agronomists who provided feedback (Annex IV) found the sticky trap system easy to set up, but had problems collecting them, especially when windy because the A4 sleeves were too flexible. Some refinements would be needed if they were to be widely adopted. A weekly collection was regarded as optimal, partly because the traps also caught many other insects, especially flies, making it harder to discriminate the aphids. Further trials are needed to test whether other colours or transparent traps would reduce the by-catch yet still capture sufficient aphids.

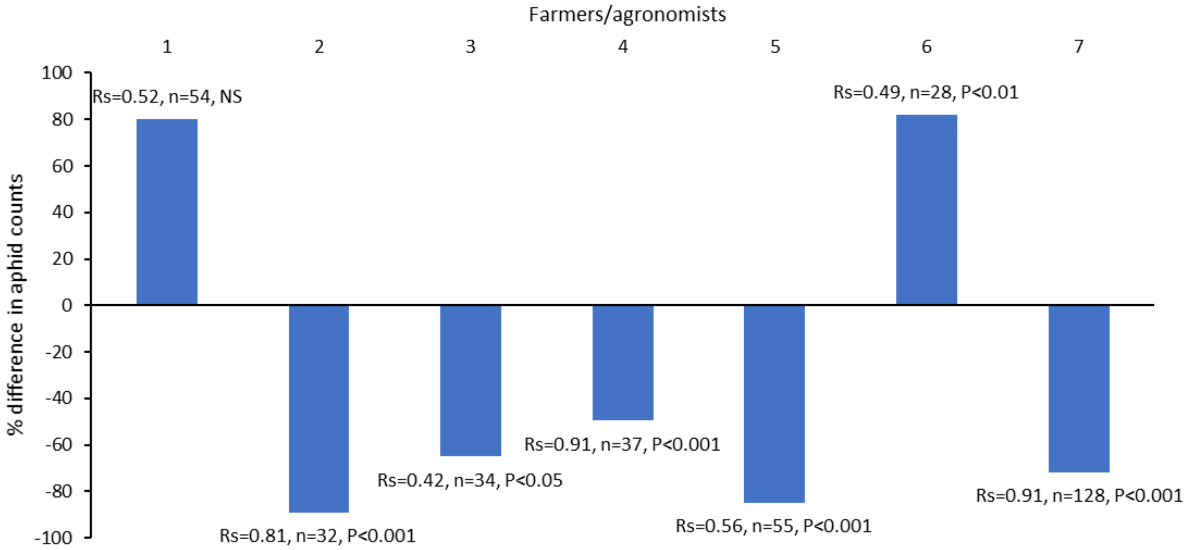


Figure 20. Difference in the number of cereal aphids identified by farmers/agronomists compared to experts. For each person the Spearman's rank correlation (Rs), number of sticky traps assessed (n) and whether the correlation was significant is shown (P value, NS=not significant).

The users thought that their identification skills were improved by taking part in the study, however, the results above showed that they were still mis-identifying a large proportion of the aphids. This was, however, with minimal training. In future a guide would be needed with better pictures and depicting aphids caught on the traps. A training video would also help so that an expert could guide them through the process. The majority of farmers involved in the trial would like this training. The time taken to identify each trap varied considerably (1-14 minutes) but was not in relation to the number of aphids they were finding. Experts were taking between 5-15 minutes depending on the numbers of aphids.

Three of the users believed the traps were providing an indication of aphid levels in the field but the other three were unsure, yet even when unsure the results were still influencing their agronomy decisions (Appendix IV). Four of the six adjusted their agronomy decisions because of their trap results, but only one reduced insecticide usage. They would all like to use the system in the future and in approximately 4 fields on their farm or group of farms under their management.

Within-field spatial variation of immigrating winged aphids

A total of 396 sticky traps were deployed across the two fields catching 3,337 (90%) grain aphids, 58 (1.5%) bird cherry-oat aphids and 75 (8.5%) rose-grain aphids. The more detailed study of cereal aphid distributions within two fields was analysed using SADIE, a statistical approach specifically developed for identifying spatial pattern in count data. The SADIE analysis showed that the total numbers of aphids in Dorset was significantly aggregated into patches and gaps from the second sampling occasion onwards (Table 4). The total numbers of aphids, each aphid species and the natural enemies all showed strong aggregation into patches with gaps between them. The patches of aphids were located predominantly in the south-east corner of the field adjacent to the woodland (Fig. 21), although some patches occurred within the field in the last sampling period. (Fig. 22a). The total number of both aphid species, grain and rose-grain aphids and the natural enemies all showed the same spatial pattern (Fig. 23a). The wind direction during the sampling period varied considerably with south-east to south-west winds prevailing during the first half of the month and north-east during the second half switching to south-west.

Table 4. SADIE analysis of the aphid and natural enemy spatial distributions within the fields in Dorset and Hampshire. (TA=Total aphids, RGA=Rose-grain aphid, GA=Grain aphid, NE=Natural enemies). I_a and its associated probability P_a indicate the overall degree of clustering; Values of I_a = 1 indicate randomly arranged counts, whilst $I_a > 1$ indicates aggregation of counts into clusters and $I_a < 1$ indicates regularity. Mean v_j is the average over all inflows indicating presence of clustering into gaps and its associated probability whereas Mean v_i is the average over all outflows indicating patchiness with associated departure from non-randomness.

Dorset	**TA Date 1**	**TA Date 2**	**TA Date 3**	**TA Date 4**		**RGA**	**GA**	**TA**	**NE**
I_a	0.99	2.11	1.53	2.17		1.55	1.56	2.02	1.57
P_a	0.44	0.00	0.02	0.00		0.02	0.02	0.00	0.02
Mean v_j	-0.99	-1.92	-1.50	-2.15		-1.54	-1.35	-1.82	-1.36
Mean v_i	0.91	2.07	1.36	2.02		1.41	1.59	1.87	1.59
P_j	0.44	0.00	0.03	0.00		0.02	0.06	0.00	0.06
P_i	0.64	0.00	0.05	0.00		0.04	0.01	0.00	0.01
Hampshire	**TA Date 1**	**TA Date 2**	**TA Date 3**	**TA Date 4**		**RGA**	**GA**	**TA**	**NE**
I_a	1.52	1.38	1.62	1.73		1.55	1.51	1.48	1.18
P_a	0.03	0.06	0.02	0.01		0.02	0.03	0.03	0.18
Mean v_j	-1.43	-1.31	-1.43	-1.55		-1.54	-1.43	-1.42	-1.13
Mean v_i	1.19	1.55	1.56	1.54		1.41	1.61	1.50	1.19
P_j	0.05	0.09	0.05	0.02		0.02	0.05	0.05	0.22
P_i	0.15	0.02	0.02	0.03		0.04	0.01	0.03	0.15

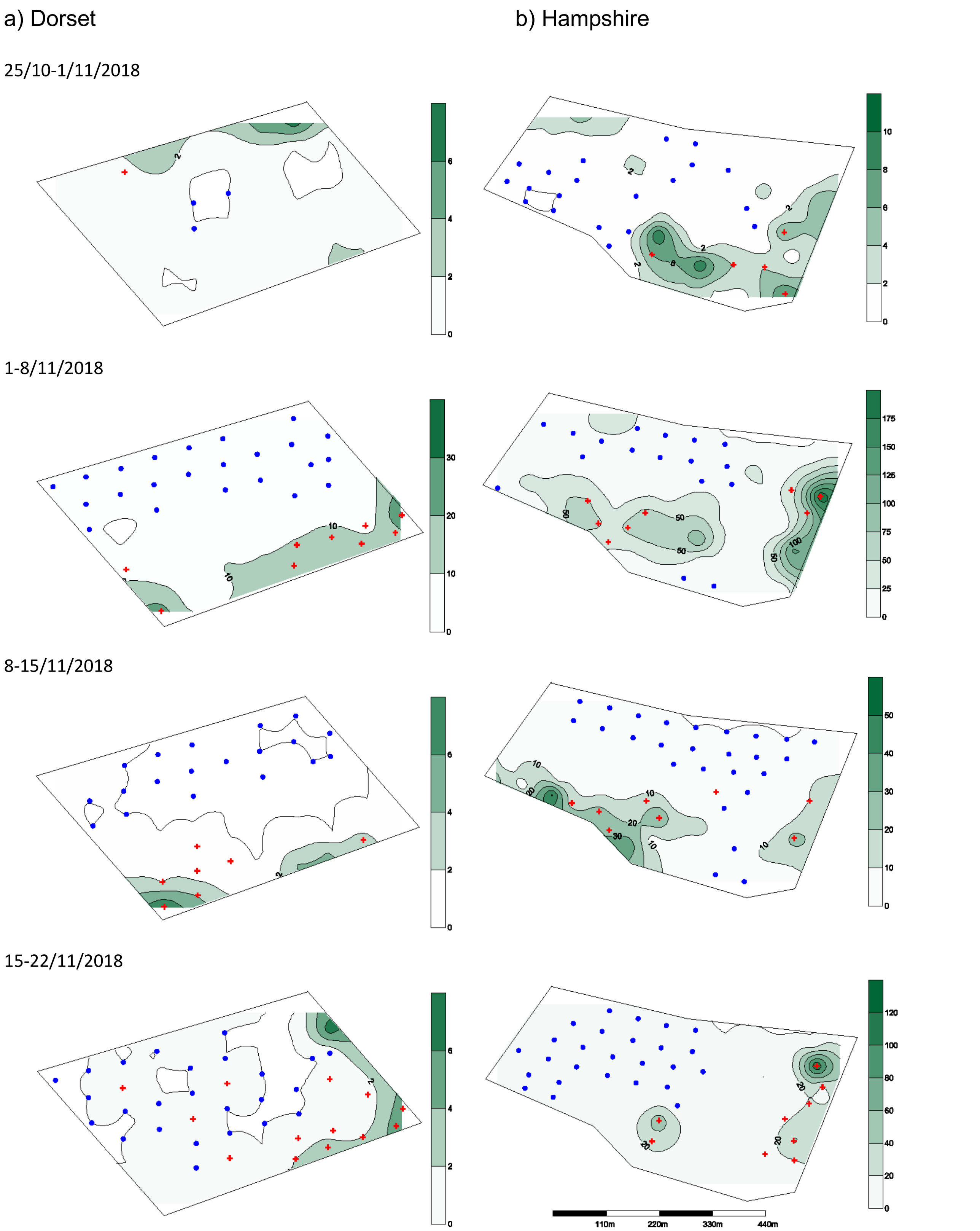
In Hampshire, the SADIE analysis also showed strong aggregation of the aphids into patches with gaps between them on all sampling occasions and for the total numbers of aphids and each aphid species but not the natural enemies (Table 4). For the total aphids the patches were located in the south and eastern edges of the field near to the hedgerows and a small coppice of trees (Fig. 22a).

The patches of the two aphid species also occurred in these areas as did the natural enemies (Fig. 23b). The wind direction during the sampling period varied from south-east to south-west for the first half of the month, switching to northerly and north-easterly for a week followed by south-west winds at the end of November.

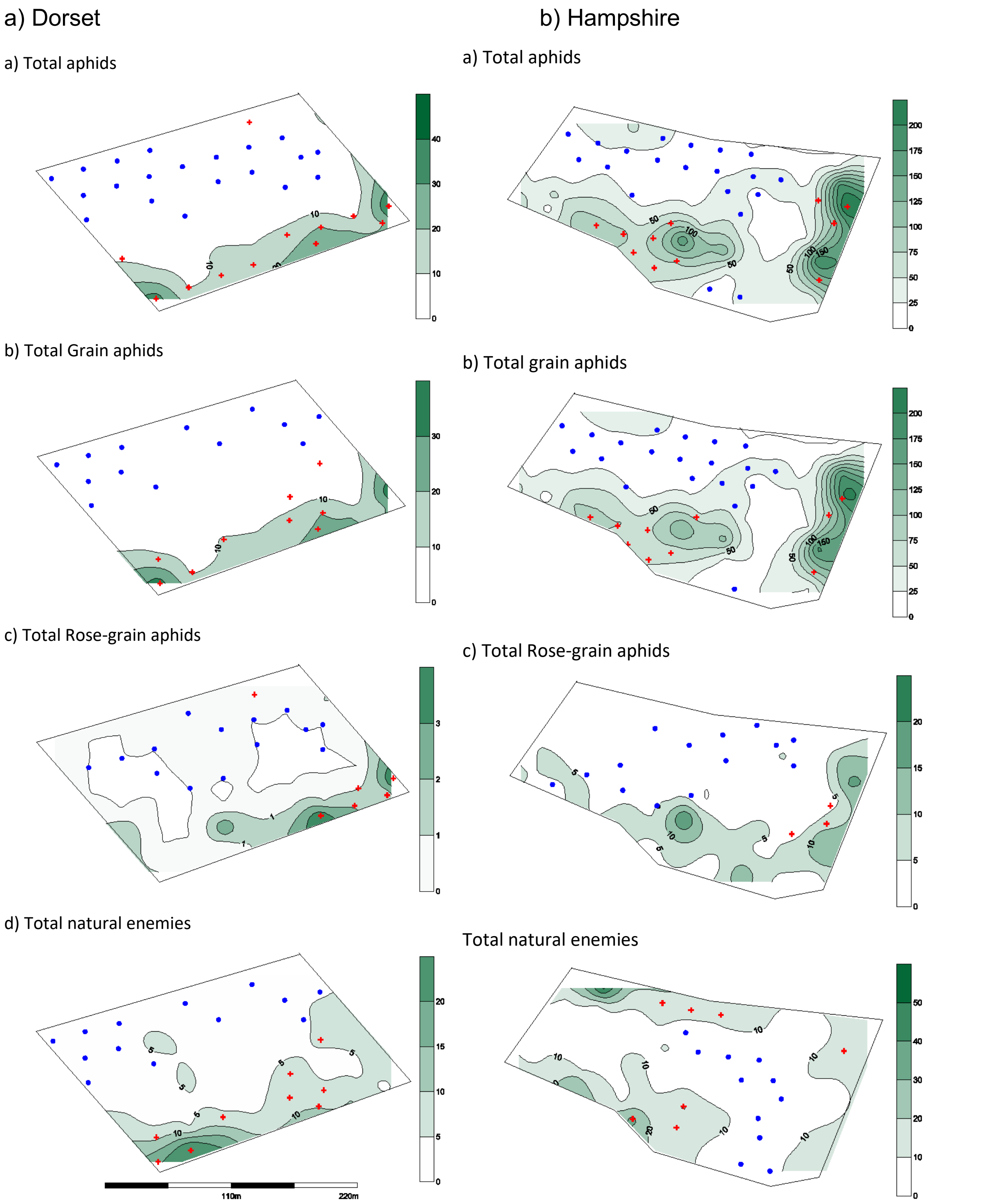
For both sites the highest numbers of aphids were captured during the first week of November (Fig. 22a & b), when the wind was from south-east to south-west.

b)

Figure 21. Location of sampling points for the fields in Dorset (a) and Hampshire (b), maps are aligned north-south with the page border.



Figures 22a & b. Spatial distribution of cereal aphids collected using sticky traps within the fields in Dorset and Hampshire on the four sampling occasions. Significant patches are indicated by red dots and gaps by the blue dots. Values are number of aphids/trap.



Figures 23a & b. Spatial distribution of the total number of cereal aphids and natural enemies within the fields in Dorset and Hampshire collected on the sticky traps. Significant patches are indicated by red dots and gaps by the blue dots. Values are total number of aphids/trap.

Optimising sticky trap identification

To investigate whether the effort needed to assess the traps could be reduced by only counting 1-4 quarters, a Box-and-whisker plot was compiled (Figure 24.) This shows that the median value was similar for when three or four quarters were assessed per sticky trap, 2.66 and 3 respectively. Assessing two quarters gave an underestimate (median = 2) whilst assessing one quarter gave an overestimate of aphid numbers (median = 4).

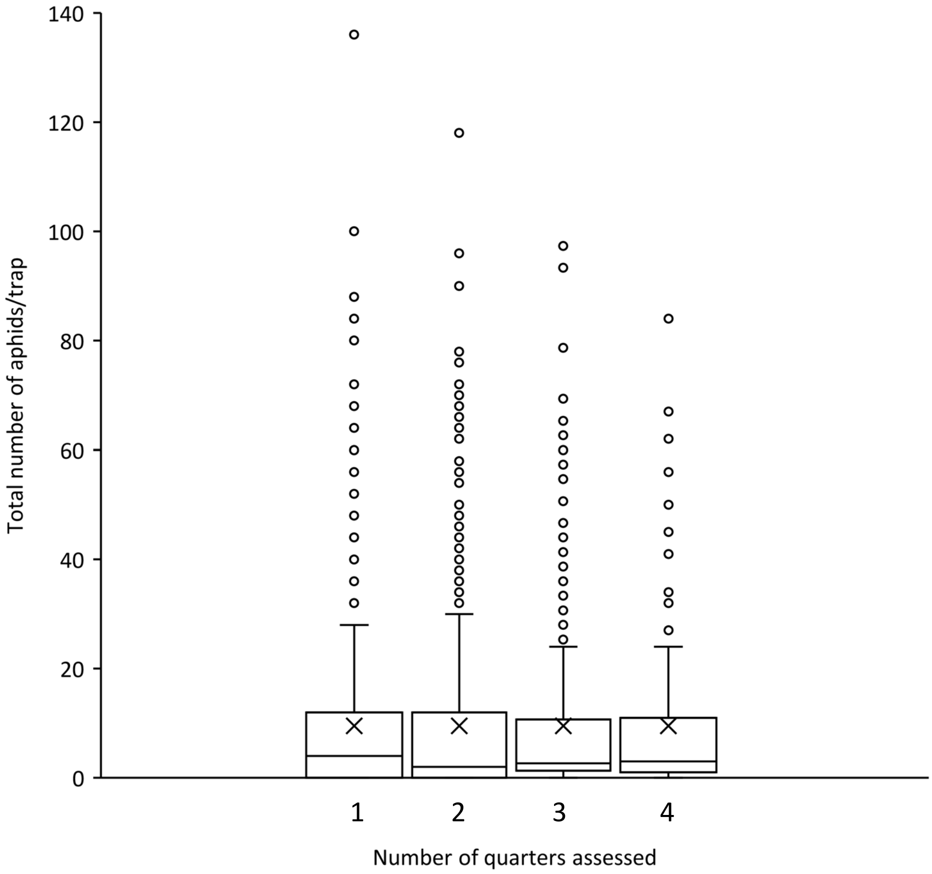


Figure 24. Box-and-whisker plot for when aphids were included for 1-4 quarters of each sticky trap. Plot shows mean (x), median (horizontal line within the box), lower quartile (lower limit of box), third quartile (upper limit of box), whisker extends to 1.5 times the interquartile range, outliers that are beyond this range (o)

4.2.3. Assessment of BYDV virus levels within aphids

a) Time for which positive samples remain detectable by the virus assay in the field

Levels of PAV infection for aphids deployed in the field up to 14 days were compared to that of the controls. There was no significant difference at 0 and 3 days, but there was significant reduction in PAV score by PCR assay at each of 7, 10 and 14 days compared to the control ($p<0.05$). Half of the aphids tested at 7 days and beyond still tested positive for the virus (Bates et al., submitted).

b) Variation in localised aphid infectivity levels

A total of 253 aphids were tested of which 8 (3.2%) tested positive for BYDV-PAV. Equal numbers of grain and rose-grain aphid were infected and all were collected at 5 m from the crop edge in one of the fields. The traps were deployed for 14 days and therefore this overall infection level is likely to be an underestimate as the previous study showed detection levels declined beyond three days.

4.3. Effect of trap size, boundary type, landscape composition and type of tillage

4.3.1. Effect of trap size, boundary type, landscape composition and type of tillage on immigration of aphid vectors caught on sticky traps

Variation between and within fields in aphid immigration

To gain an initial understanding of the variation in the levels of cereal aphids between and within fields, data was pooled from the farmer trials of sticky traps (3.2.2) and landscape studies (3.3.1) for two periods early to mid-November and mid-November to early December as this was the time when most fields were sampled across the two studies. Data was used from farms located in Dorset, Hampshire, Leicestershire, West Sussex, Wiltshire and Yorkshire and included 21 farms and 48 fields (Figs. 24 & 25).

For early to mid-November, at 5 m from the crop edge, no aphids were captured in 16% of the fields, <5 per trap per day were caught in 64% and 19% had more than 5 per trap per day. At 70 m into the field, there were fewer aphids with 24% having no aphids for both periods, 72% having less than 5% and only 4% had more than 5 (Fig. 24). From mid-November to early December, at 5 m from the crop edge, again 16% had no aphids, 83% had less than 5 aphids and none had over this level. At 70 m, 24% had no aphids, 76% had less than 5% and none had more than 5 (Fig. 25). There were often several fold difference in the numbers of aphids caught on the same farm.

Results from the farmer-run study

The farmer's study (3.2.2) allowed the effect of trapping location within the field and type of tillage to be investigated. This analysis revealed that significantly more winged grain aphids, bird cherry-oat aphids, total winged aphids and natural enemies were caught at 5 m compared to 70 m from the crop edge ($P<0.001$) but there was no effect of the different cultivation types (ploughed, minimum tillage or direct drilled) for any of these groups.

Results from the landscape study

A total of 370 sticky traps were deployed catching 3,929 (80%) grain aphids, 1,642 (13%) bird cherry-oat aphids and 75 (7%) rose-grain aphids. The landscape study (3.3.1) was designed to test for the effect of sampling location, tillage, boundary type, proportion of grassland in the surrounding landscape and trap size. Using data from both the small and large traps the data was first analysed to test for the effects of distance from the boundary and type of tillage.

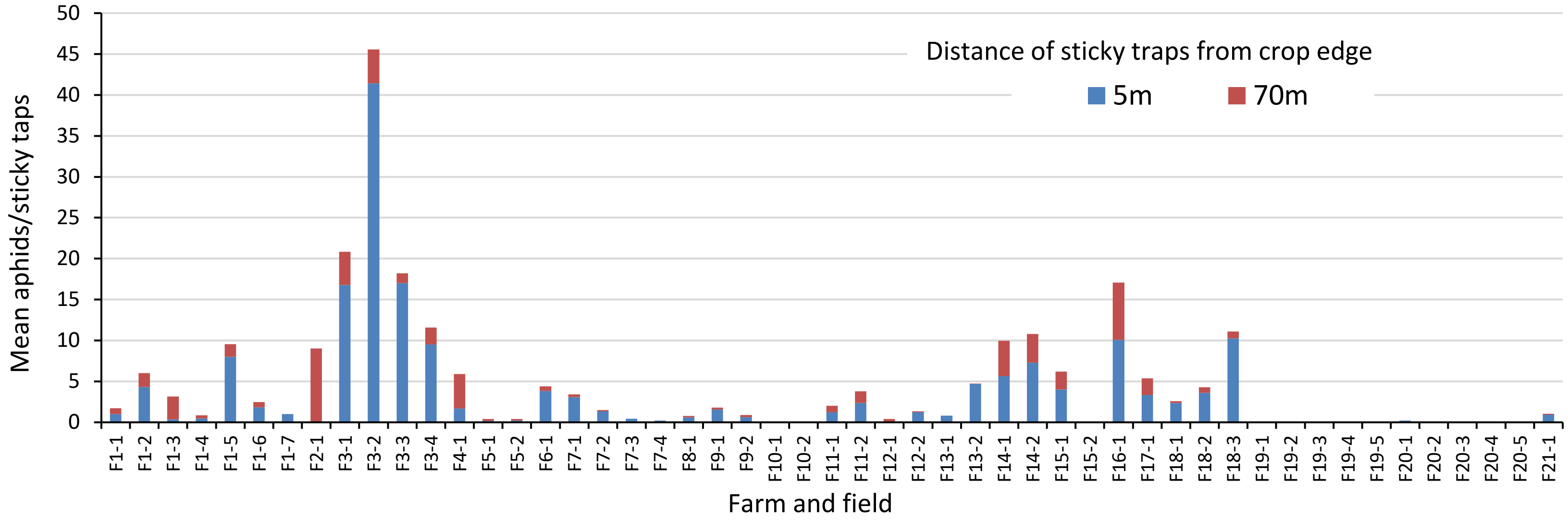


Figure 25. Mean number of cereal aphids on sticky traps located at 5 and 70 m from the crop edge for sampling conducted in early to mid-November.

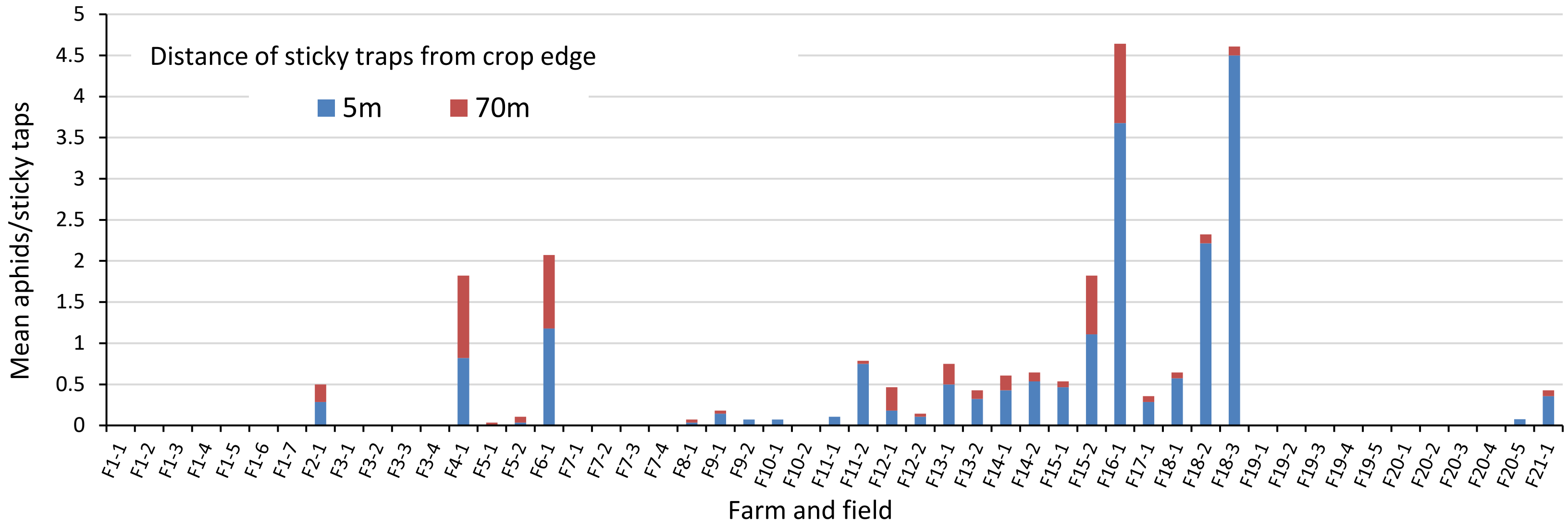


Figure 26. Mean number of cereal aphids on sticky traps located at 5 and 70 m from the crop edge for sampling conducted in mid-November to early December.

As found in the farmer-run study, significantly more (P<0.001) winged grain aphids, bird cherry-oat aphids, total winged aphids and natural enemies were caught at 5 m compared to 70 m. Significantly more (P<0.05) natural enemies were captured on traps in ploughed fields compared to those that were established using minimum tillage, but there was no effect on the total numbers of aphids.

The analysis of the effect of grass coverage in the landscape revealed that significantly (p<0.05) fewer total numbers of cereal aphids on sticky traps when grass coverage in the landscape was low compared to high. The same trend occurred for the most abundant species (grain aphids) with almost significant results (P=0.057), but no effect was detected for bird-cherry-oat aphids or natural enemies, however these occurred in much lower numbers.

Significantly fewer grain aphids (P<0.001), bird cherry-oat aphids (P<0.01), rose-grain aphids and total aphids (P<0.001) were caught on the smaller sticky traps after correcting for trap size. After correcting for trap size, the mean number of aphids was 10.1 and 6.3, whilst the median was 3 and 2 for the larger and small traps respectively (Fig. 27).

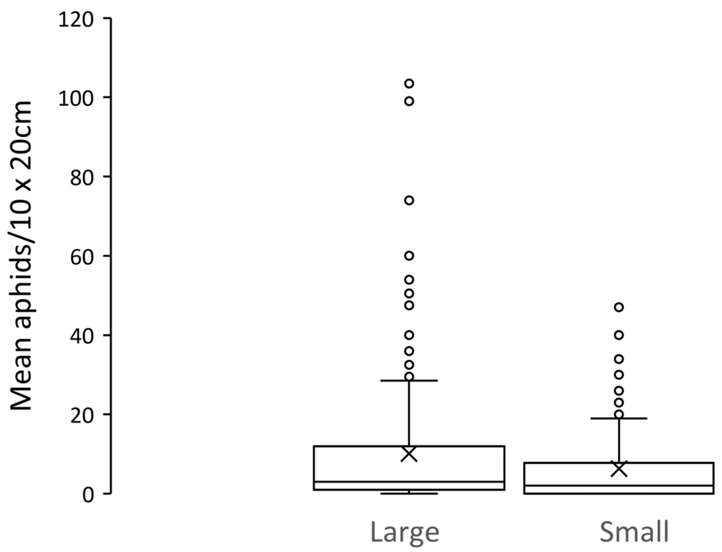


Figure 27. Box-and-whisker plot of cereal aphids corrected for area for the large and small traps. Plot shows mean (x), median (horizontal line within the box), lower quartile (lower limit of box), third quartile (upper limit of box), whisker extends to 1.5 times the interquartile range, outliers that are beyond this range (o)

When the effect of crop type, sampling occasion, boundary type and distance from the boundary were analysed for each trap size, more significant effects were detected with the larger traps

(Table 5) and the data was too abnormally distributed to allow analysis of the bird cherry-oat aphids caught on the smaller traps. Only data from the larger traps is therefore considered.

Table 5. Results of analyses for the small and large trap sizes testing the effecting of crop type (compared to winter barley), sampling occasion (compared to round 1), boundary types (each compared against a grassy strip), and distance (compared to 5 m). Higher or lower indicate if given factor was higher or lower to comparison. (WW=winter wheat, WB=winter barley, H=hedgerow, TL =tree line, W=woodland, NS=not significant, almost significant $0.05<p<0.1$)

Small traps (10x20 cm)

	Grain aphid	Bird cherry-oat aphid	Rose-grain aphid
Intercept (WB, Sampling occasion 1, boundary grass, distance 5m)	NS		NS
Crop type (WW)	NS	*Won't*	NS
Sampling occasion (2)	Lower ***	*converge*	Lower **
Boundary (H)	Higher almost significant		NS
Boundary (TL)	NS		NS
Boundary (W)	Higher almost significant		NS
Distance (70m)	Lower ***		Lower ***

Large traps (20x20 cm)

	Grain aphid	Bird cherry-oat aphid	Rose-grain aphid
Intercept (WB, Sampling occasion 1, boundary grass, distance 5m)	NS	NS	NS
Crop (WW)	NS	NS	NS
Sampling occasion (2)	Lower ***	Lower almost significant	Lower ***
Boundary (H)	Higher almost significant	NS	NS
Boundary (TL)	NS	NS	NS
Boundary (W)	Higher *	NS	NS
Distance (70m)	Lower ***	Lower ***	Lower ***

On the larger traps, there was no difference in the numbers of the three aphid species between the two types of cereal crops. Fewer aphids were caught during the second compared to the first sampling period (P<0.05) for grain and rose-grain aphids. At least twice as many cereal aphids were caught at 70 compared to 5 m (P<0.001) (Fig. 28) for all three species. Significantly (P<0.05) more grain aphids were captured in fields adjacent to woodland compared to grass strips, with high numbers also being caught next to the treeline boundaries, however there were only eight replicates of this habitat and high variability between them which reduced the chance of detecting any significant difference compared to the other habitats (Fig. 29).

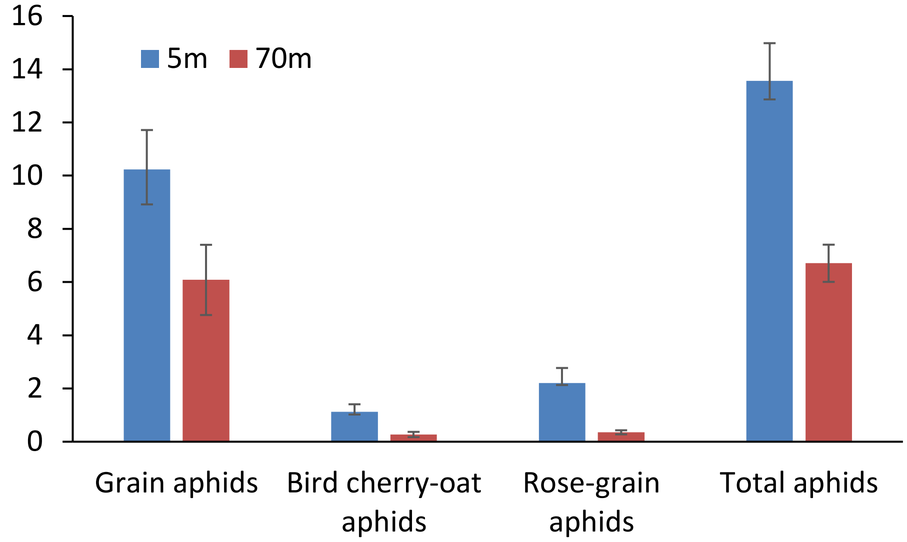


Figure 28. Mean number of cereal aphids per trap at 5 and 70 m from the crop edge on the larger sticky traps.

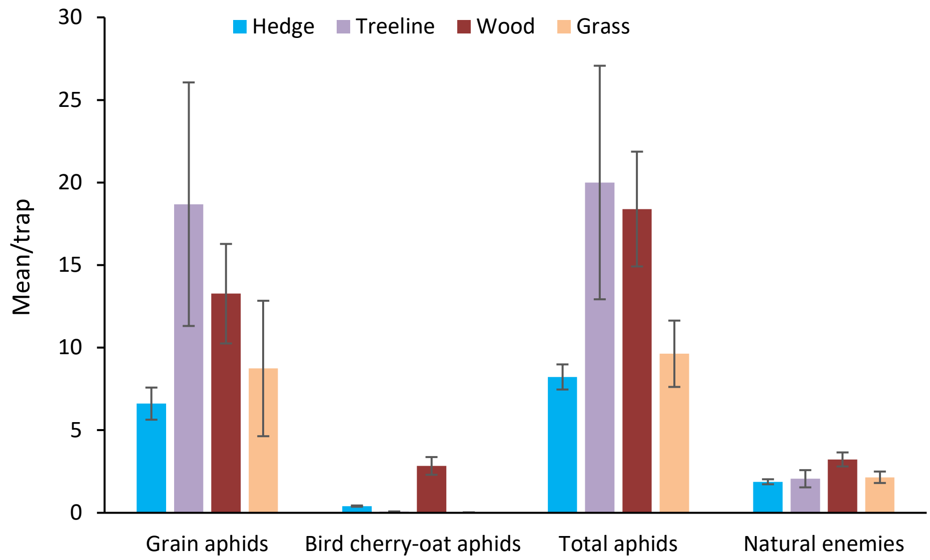


Figure 29. Mean number of cereal aphids and natural enemies in fields with different boundary types.

4.3.2. Effect of tillage on aphid immigration and natural enemies in the crop

There were no significant effects of sampling location or cultivation type on the mean numbers of grain aphids, rose-grain aphids, total aphids or natural enemies collected by Dvac sampling for the farms in Hampshire and Wiltshire. In contrast, numbers of total aphids captured on the sticky traps for the period prior to Dvac sampling was significantly higher ($P<0.001$) at 5 m (raw mean of 118/trap) compared to 70 m (raw mean of 10/trap) and significantly lower ($P<0.05$) in the ploughed (raw mean of 44) compared to non-inversion tillage fields (raw mean of 85). There were also significantly more ($P<0.001$) grain aphids at 5 m compared to 70 m (raw mean of 44/trap at 5 m and 7/trap at 70 m) and likewise for bird cherry-oat aphids ($P<0.01$) (raw mean of 73/trap at 5 m and 3/trap at 70 m). Neither sampling location or tillage type had an effect on the numbers of natural enemies on the sticky traps. This indicates that despite more aphids invading the headlands and non-inversion tillage fields, this was not leading to higher levels establishing in the same areas, however this may be because the treated seed was still preventing colonisation.

On the two BASF farms very few aphids (15) were collected in the Dvac samples from 18 fields, however from one direct drilled field 137 were collected. The data was therefore not analysed. A total of 53 natural enemies were captured in the Dvac samples, but there was no significant effect of cultivation type (direct drilled or minimum tillage) on their numbers.

5. Discussion

5.1. Review of decision tools for BYDV

5.1.1. Potential for a decision support tool

It is recognized that M007 and M008 should be considered for further research work. Both entries refer to work carried out in the UK, they take into account both bird cherry-oat aphid and grain aphid and they simulate the spread of BYDV by using temperature and suction trap data as input. These are all considered relevant characteristics for future development of a new decision support tool for aphids and BYDV management. Entries M004, M005, M009 and M011 were at this stage deemed not suitable for future work, it is not excluded that should attempts to adapt and adopt entries M007 and M008 fail, the initially excluded works could be used to evaluate/replicate possible approaches for building models from start and also including grain aphids.

A few considerations need to be made on the challenges and extent of work needed to test and adapt these systems before reaching a tool ready for deployment. First of all, there is an issue related to the retrieval of the full models and coding as they may no longer exist; the next stage is to contact the original researchers involved in the development of M007 and M008, although many have now retired. Secondly, in respect to the input there is a need to verify whether suction trap data could be substituted by sticky trap data, which will also bring the decision support tool immediately to a field level. The survey carried out within the current project showed that about 70% of the respondent farmers are willing to monitor yellow sticky traps at a weekly interval. Also, it resulted that an “ideal” decision support should consider weather factors (e.g., T-sum), threshold based on field observations, and information related to the aphids such as presence of virus and resistance status to insecticide. Thirdly, the output should ideally relate to the likely severity of BYDV and resulting crop loss so that the decision around the appropriateness of an insecticide application can be made based on tangible risk of potential income loss. Also, according to the survey, the support should provide information on the impact of drilling date, variety choice and cultivation options. The surrounding landscape composition and distance from the coast have also been shown to be influential and there exists the possibility that risk is constant and therefore some fields will always be low or high risk. Fourthly, an evaluation of the costs for the development of the software and digital framework for delivering the service is needed, but this is beyond the scope of this project. Finally, the validation and test phase, ideally, have to be carried out over a sufficient number of years per site to build up confidence in the users by demonstrating the scientific robustness of the system.

Entries M007 and M008 largely satisfied the requirements for the input and outputs. Yet, in respect to the input, work is needed to validate the use of yellow sticky traps and the inclusion of information related to the aphids (virulence and insecticide resistance status). In terms of output, the quantification of the risk and the support around drilling date, variety choice, cultivation and landscape composition options need to be addressed.

Some relevant insights on the issues related to the nature of the input and the output could be derived from the field work carried out during this project and the present literature review.

Input

The current study highlights the extent of variation in levels of invading winged aphids within fields with three and half times as many cereal aphids landing on sticky traps located in the headland compared to 70 m into the field. The type and height of boundary features in relation to the prevailing wind appear to be influential in determining aphid deposition and offers an additional opportunity for modelling to help identify high risk locations. The current project also revealed large variation between fields, even on the same farm, with 16% having no aphids and a large proportion, *ca*. 64-83%, had relatively few (<5 aphids per trap per day) depending on the sampling period. The accuracy and time required to assess sticky traps relative to crop walking, and their relative accuracies with respect to any treatment threshold still needs to be assessed. However, such level of variation offers an opportunity to develop IPM approaches and selective spraying that is field specific or even within-field specific. The original study in P004 (the results of which are embedded in the decision support of entry M007) also assessed field characteristics of 623 fields in relation to autumn aphid abundance and spring BYDV levels, but where the assessments were made in respect to distance or direction from field boundaries is not described (as far can be ascertained). Surrounding land use was measured and the following features identified as important: crops closer to the sea, surrounded by non-arable land and fields either east (MAV) or south-west (PAV) facing. P001 and P003 also focused on land use and showed how this can affect the proportion of colonizing bird cherry-oat aphid as well as their viruliferous status. However, cultivation and establishment techniques did not appear in this study to be influencing the abundancy of immigrating aphids, unlike in P002 and P005. The latter also observed an effect on the presence within the crop of aphid predators. This project also verified some of the above, with the presence of more grassland (non-arable) increasing aphid infestation levels, and natural enemy distributions often matched that of the aphids.

Given the limited number of suction traps across the UK and the large gaps in their distribution, it is unlikely that they will be able to capture the variation that occurs between fields at the farm scale. In addition, the relationship between capture on the sticky traps and that in the suction traps is limited to one small study which was part of M007. In this study, sticky wire traps were placed 250m, 750m and 39 km from a 12.2m suction trap. Given this limited testing this relationship needs further testing to determine how accurately the suction traps predict aphid capture timing and relative abundance on traps across the range of distances for which they need to cover. If this proves to be inaccurate for all cereal producing areas then the sticky trap system has the potential to provide more local data and could be used now for timing the start of immigration by winged aphids in conjunction with a T-sum tool.

Output

The idea of providing an output related to likely crop yield losses due to BYDV has a great potential in that it will allow evaluation of the appropriateness of spraying based on the risk of economic repercussion. Relations between BYDV incidence and crop loss were included in M007 and are listed in the final report of the MAFF-funded project AR0308, they were also the core of entry M011. According to this work, the area under the curve of the percentage of plants infested by bird cherry-oat aphid during autumn was highly significantly related to BYDV yield losses. Based on this, cost/benefit analyses were performed and a threshold for spray intervention was identified. As discussed above, the possibility of assessing the level of infestation by means of a quicker and less invasive monitoring method, such as the yellow sticky traps tested in the current project, will be preferable to carrying out observations directly on the plants. The authors of M009 reached a similar conclusion. They investigated possible predictors of the risk of BYDV infections and found the most reliable ones to be the proportion of infested plants and to a lesser extent the numbers of trapped aphids. Nevertheless, at a practical level, the authors recognized that the use of counts of aphid catches would seem a better compromise between accuracy and consistency of prediction and ease of gathering data than that of plant infestation in which other factors such as light levels influenced the observer's accuracy. At the same time, they recognized that any significant improvement of the prediction should be sought in an early estimate of the amount of virus available to aphids before they colonise the plants. This point is reiterated also in entry M008, one of the most promising work reviewed as part of this project. Although their model adequately described the spread of BYDV, the authors highlighted that their current methodology of regular monitoring of aphid field populations and their vector status is very labour-intensive (the infectivity of autumn migrant aphids was measured by feeding transmission tests). They concluded by envisaging that further progress towards a practical decision support would have heavily depended on the future development of simpler, more rapid and cost-effective methods of sampling and diagnosis. If the current project seems to have identified a simple monitoring system at field level, questions still need to be answered about the necessity of knowing the number of infected aphids required to cause significant crop losses.

In the reviewed works recommended for further investigation, the issue of the initial proportion of aphids carrying the virus has been dealt with by means of the past average (M007) and the infectivity status of the migrant aphids with the assumption that 5% of aphids migrating into the crop are likely to carry BYDV if none tested positive (M008). A similar assumption, but with no need of infectivity testing, was used in entry M002. Both M007 and M008 then simulate the virus spread in terms of percentage of plants infected by calculating the virus acquisition and inoculation as a function of temperature. Fieldwork carried out in France found the proportion of viruliferous bird cherry-oat aphids migrating into crops to be of similar magnitude: 5.25 % in P001 and 4.98% in P003. The small study in the current project also found a 5% infection rate when the virus was present. The absence of any virus in aphids collected only 2.5 km away and the variation in the proportion of viruliferous aphids occurring between the Suction trap network sites also indicates that with such local variation it may not be worthwhile trying to identify localities with no infected aphids. A minimum level of 5% level everywhere could be assumed as done in M007 or alternatively utilise the results from the Suction trap network to provide guidance.

If an economic threshold is to be developed based upon aphid levels on the sticky traps then the relationship between numbers of aphids on the traps, the proportion that survive to infest the crop and levels of BYDV infection would need to be identified in conjunction with other variables that may affect both aphid survival and virus development such as crop, variety, weather, natural enemy levels and sowing dates. In the research process the proportion of plants can be used as surrogate indicator of virus levels which would be cheaper than conducting molecular tests. M007 showed that there was a strong correlation between virus levels and the proportion of plants showing symptoms. The advantage of the system is that it could provide very local, field or farm specific recommendations but will depend on the assessor accurately identifying aphids on the traps.

5.1.2. Survey of farmers and agronomists

In terms of current practice, the survey showed that about half of the farmer respondents and one third of the agronomists have been relying solely on the insecticide coated seed to provide protection against aphids. These will be the people most affected by the ban and further support for them to adapt their pest management practices would be needed and welcomed. An overwhelming 92% of the responded indeed expressed the need of receiving more support and information following the ban. This high percentage shows that this need is felt also by the rest of the respondents, who relied on insecticide foliar application only (10%) or on a mixed approach (seed dressing only or followed by foliar application/s on parts of their farms). These respondents have already been facing the issue of deciding if and when to spray and it appears that their decision was most often based on calendar: “drilling date” was selected by more than 25% of respondents of both types. Reassuringly though, the other most frequent criteria adopted were the presence of aphids on the crop (for both type of respondents), and the crop growth stage and the T-sum Calculator for agronomists.

Awareness and practice of IPM was declared by over 90% of the respondents, with four out of five of the IPM options listed having been adopted by at least 45% of the respondents. Conservation tillage was the least popular choice, perhaps due to its unclear role in aphid management and being a practice most commonly sought after for soil structure and nutrition benefits. Indeed, the results in the study indicate that the practice is not inhibiting aphid immigration. Conservation tillage can also allow a green bridge to survive and may also explain the farmers’ caution. On the other hand, other studies have shown that natural enemies are higher when conservation tillage is practised. Among the most frequent sources of information, currently used to support decisions around aphids/BYDV management, are AHDB Aphid News and a T-sum Calculator. These results are encouraging as they indicate that the target audience has an understanding of IPM and most likely will adopt an IPM oriented decision support, which combines monitoring and field specific risk factors and is delivered in the form of a digital tool. A better estimate of risk at field level appears to be most desirable, and 8-10% of respondents already recognised that inadequate estimation of aphids/BYDV risk was to blame when BYDV unexpectedly developed in their crops.

The responses, collected in the survey section dedicated to decision support, further back this expectation. More than 50% of farmers and 75% of agronomists are already using monitoring and decision support tools for crop protection, more than 70% are willing to dedicate time to a new tool and 90% of farmers expressed willingness of monitoring sticky traps on a weekly basis.

The “ideal” decision support for aphids/BYDV management should consider weather factors (T-sum), thresholds based on field observations, and information related to the aphids such as presence of virus and resistance status to insecticide. Whilst the first factors (weather factors and aphids scouting and/or trapping) are feasible in the immediate future, the last two factors seem expensive at this stage and involving complex logistic for sampling, preservation, delivery and analysis at a specialised laboratory, unless portable in-field tests are developed. Other field-specific factors, also deemed important by the respondents to be included in the support tool, were: drilling date, variety choice, cultivation options and stubble/green bridge management. This project also found that risk factors also include boundary type and proportion of grassland in the landscape.

In terms of delivery, the most desirable features were for the decision support to be released as a mobile app, including push alerts via email.

5.2. Evaluation of field-specific monitoring methodology of aphid vectors of BYDV

5.2.1. Predictive capability of aphid monitoring

All of the studies confirmed that the sticky trap approach is effective for capturing BYDV vector aphids and that considerable variation occurred in the numbers found, both within and between fields. Even only one trap per location (5 and 70 m) within a field was enough to detect substantial differences between the crop headland and mid-field. Substantial differences were also found between fields indicating that the approach is sensitive enough as a monitoring system. In addition, several-fold differences in aphid immigration were also found between fields on the same farm therefore indicating that sticky traps would need to be operated on more than one field per farm. The farmer survey indicated that approximately 4 fields per farm would be relatively easy to monitor.

Unfortunately, over all of the studies in which aphids were measured both on sticky traps and on the plants, very few aphids were found on the crop, however with the exception of the trial conducted by Agrii in Essex and five of the fields in Kent, seed was treated with a neonicotinoid insecticide and therefore this may have persisted long enough to prevent aphid colonisation. In addition, there was considerable unsettled weather, with cold, wintery conditions at the end of October, followed by frequent rainy days during November that may have reduced aphid levels on crops. Consequently, further work is needed to confirm how well they predict levels of aphids establishing within the crop when seed is untreated and conditions are favourable for aphid survival.

Overall few aphids were found within the crop in the Agrii trial (4.2.1) despite aphids being captured on the sticky traps and indicates that substantial aphid mortality occurs before they can colonise the crop. This may be as a result of predation or parasitism, capture of natural enemies on the sticky traps confirmed they were also active at this time of year, or they failed to reach the crop, rainfall and a wet soil surface can inhibit movement. However, despite there being few aphids on the crop in the Agrii trial and BYDV symptoms only being found on 2.7% of plants, a 0.5 t yield increase was obtained when an insecticide was applied. The application was close to when most aphids invaded the crop. The regression analyses confirmed that the yield loss was related to the proportion of BYDV infected plants. The sticky traps indicated that an influx of bird cherry-oat aphids occurred in mid-October and overall levels of this aphid species were positively correlated with the yield decrease, although not with the proportion of BYDV infected plants. These results suggest that the sticky trap approach has merit as a predictive monitoring tool, especially given that this was only a small trial. More extensive trials to quantify the relationship between capture on sticky traps, levels of BYDV and subsequent yield loss are needed if a spray threshold is to be developed based upon sticky trap captures.

5.2.2. Reliability and practicalities of the sticky trap approach

Farm trials using unsprayed plots

The farm trial conducted in Kent and Wiltshire aimed to confirm whether there were correlations between aphids collected by the sticky traps, levels on the plants and plants infected with BYDV. As in the trial conducted by Agrii, few aphids were found within the crop despite them occurring on the sticky traps and there was no sign of BYDV on the plants in April in either Kent or Wiltshire. In Kent all but one field had untreated seed but in Wiltshire all fields were treated. Treated seed may have controlled aphids sufficiently until the main risk period had passed, especially when rainfall inhibited aphid survival on the crop.

Farmer trials of sticky traps

These trials demonstrated that the farmers were willing to use a within-field monitoring system on up to four fields on their farms. They considered a weekly sampling regime optimal which would also provide the accuracy to be used in conjunction with T-sum for timing of subsequent insecticide applications. The trials did however identify that their ability to identify aphids would need improving and the easiest way to achieve this would be through specific training. They expressed a need for a higher quality pictures, but this would be best supported with a video to better describe the key features that they need to use and to help reduce confusion with other insects. In addition, better training for agronomists should be provided through BASIS and their CPD programme. Some improvement to the sticky trap system are also needed such as having a margin around the edge of the trap that isn’t coated with glue to help handling and use of a stiffer A4 sheet to cover traps on collection. In addition, a less sticky glue might reduce the by-catch and make it easier to identify the aphids, but would have to be balanced against the need to be rain tolerant. The cost of the system is low and could be provided as a kit with the sticky traps, supporting pegs, A4 covers, usage and identification guidelines.

The feedback from the farmers revealed that most of them used some form of magnification to identify the aphids and this is recommended to improve accuracy. Magnifying glasses can be purchased with up to 10-45x magnification for £10-40. Higher magnification and those with a light source are recommended. If agronomists were to use assess sticky traps on a regular basis then a binocular microscope would be easier to use and ensure the highest accuracy. The time taken by the farmers to assess each trap varied considerably although was not considered excessive and can be conducted in the office. The investigations into the proportion of each trap that needed assessing revealed that at least three quarters of the larger traps needed to be counted and therefore it is recommended that all of the trap is assessed. If an economic threshold is developed then this could be revisited using a sequential sampling approach.

Within-field spatial variation of immigrating winged aphids

The studies in which the distribution of immigrating aphids across two whole fields was investigated confirmed that immigration was highest around the field edges and associated with boundary features (Holland et al., 2019). The mapping of the aphid distributions showed that patches of highest aphid densities occurred within 50 m of the boundary, tailing off up to 100 m. However, such patches did not occur around all boundaries but were associated with the taller ones comprised of mature trees. The highest numbers of aphids were caught at both locations during the first week of November when the wind was from south-west to south-east. These patterns persisted throughout the sampling period despite the winds changing considerably, although the prevailing wind was south-west to south-east which matched where aphid deposition would occur downwind of the taller boundary features.

These findings and those of the other studies in which more aphids were caught at 5 than 70 m would suggest that selectively spraying only the headland areas of the crop could be proposed as an IPM strategy to reduce insecticide usage, provided this occurred before the second generation of aphids and spread within the field. However, the number of infesting aphids required to cause an economically damaging BYDV infection would first need to be determined through trials to determine an economic spray threshold. Moreover, there are restrictions on the use of insecticides around field boundaries and the potential drift poses a threat to invertebrates overwintering in field margins. The use of low drift nozzles and restricting applications to very low wind conditions could help mitigate the risk.

Measuring BYDV infection in aphids collected on sticky traps

The study examining the limits of virus detection over time indicated that for at least 3 days there was no change in virus detection. At 7 days and beyond the proportion of aphids in which virus could be detected declined by 50%. Further testing is therefore warranted to determine how virus detection varies between 3 and 7 days and for a greater range of temperatures to identify the final maximum period over which the traps could be used for collecting aphids. Using the traps to collect aphids for 7 days or more is not recommended because in the field aphids may arrive on different days and consequently the final infection level is a combination of initial infection level and time spent since capture.

The testing of aphids from two fields showed that levels of infection were similar to those previously reported. In only one of the fields was virus detected in the aphids even though they were only 2.5 km apart indicates that substantial local level variation can be expected. The site with viruliferous aphids had a higher proportion of improved grassland (40%) compared to the other where it was 22%. Previous studies in the UK (Harrington et al., 1999) showed that BYDV infection varies between regions, with coastal areas having a higher risk and between fields (of 623 fields 28% tested positive over 3 years). Factors that influence aphid levels were landscape composition with more where there was uncropped land such as grassland, moorland, wasteland and virus levels were lower where arable land dominated (Harrington et al., 1999).

The current testing of aphids from the suction trap network is showing considerable variation with similar levels to those previously reported in the 1990s. In the 1990s a relatively small proportion of aphids carried the virus (typical range found by Kendall et al. (1992) was 1-10% for grain aphid and *Rhopalosiphum* species, although sometimes higher. The current testing for 2019 funded by AHDB is showing considerable variation (<5%-65%) in infection levels for bird cherry-oat aphids between sampling occasions and between the five suction traps from which samples are being tested. Very few grain aphids are being caught by the suction traps so it is not possible to obtain an accurate measure of infectivity levels (AHDB Aphid news).

5.3. Effect of trap size, boundary type, landscape composition and type of tillage

Effect of trap size

Significantly fewer aphids were detected in the captures for the two trap sizes (10 x 20 cm and 20 x 20 cm) after correcting for their area. More significant results were obtained using the larger compared to smaller trapsbecause they caught more aphids, therefore it is recommended that only the larger traps are used.

Effect of boundary type

In the landscape study (3.3.1) the effect of adjacent boundary type was tested revealing that significantly more grain aphids were caught adjacent to woodland, with an almost significant difference for hedges. There was no effect for the other aphid species, but numbers were much lower (20% of those caught). Likewise, the study of aphid spatial distributions also revealed that the highest numbers of aphids occurred in the areas adjacent to woodland or tall trees. In contrast, using the same sticky trap design, higher numbers of rose-grain aphids were caught in the headland areas adjacent to hedgerows than woodland (Holland et al., 2019). The wind speed and height of the boundary will determine the extent to the downdraft and may explain differences between the two studies. Lower numbers of cereal aphids were captured next to grass boundaries indicating that local migration from such strips into the adjacent crop was not the primary source of immigration.

Effect of landscape composition

The research conducted in the 1990s (Harrington et al., 1992) in the UK identified that having more arable land and less potential refuge habitats for aphids (e.g. areas with undisturbed grassland) in the surrounding area led to fewer cereal aphids. The analyses from the landscape study confirmed these findings for grain aphids, for which the highest numbers were captured, as less were caught where there was less grass in the landscape. Cereal aphids can survive on wild grasses during periods when the crop is desiccating or not present. These findings indicate that farms in mixed cropping landscapes, particularly if there are areas of undisturbed grassland should be more vigilant within inspecting crops for aphids and may benefit more from a farm or field-specific aphid monitoring system.

Effect of tillage

The type of tillage may influence levels of immigrating aphids because aphids are attracted to certain wavelengths of light, especially yellow, and having more crop debris could disguise the crop. Whether the type of tillage system affected numbers of immigrating aphids was tested in three studies using sticky traps, however, in none was there any effect. This would suggest that the aphids in these studies did not differentiate where they landed. This could have been because the crop debris had no impact or alternatively because the aphids were deposited mostly on the downwind side of field boundaries, deposition was passive in wind currents rather than active flight. Passive transport is considered to occur during windy weather whilst more active flight occurs in calm weather (Parry et al., 2013). There is still much to understand about the way in which cereal aphids move within the landscape.

The type of tillage may still have an impact on aphid survival once they land in a field if more natural enemies occur with a particular type of tillage, for example if more natural enemies are able to survive the mechanical impact of tillage or that a greater range of appropriate niches or microclimates are provided. However, in none of the Dvac sampling studies was there any difference in the number of aphids or natural enemies between the different tillage systems. The greatest difference would be expected between ploughed and minimum tillage fields, but this was only examined in one small study with four fields of each type. Dvac sampling also only samples a small area and more extensive sampling may be needed, especially when they are at low densities. Other methods that collect ground active invertebrates (e.g. pitfall traps) measure a combination of activity and density and are therefore not advisable, especially if insecticides are being applied that can modify food supplies and activity. Previous studies comparing ploughed and non-inversion tillage sampled using a Dvac suction sampler found fewer aphids with non-inversion, but in these cases they were assessing the numbers of aphids that survive to colonise the crop rather than their immigration (Kennedy et al., 2010; Kennedy & Connery, 2011). Even so the authors attributed the lower numbers of aphids in the non-inversion tillage fields to reduced immigration by winged aphids although aphid immigration was not measured. The lower numbers of aphids associated with reduced tillage could have been due to the greater levels of aphid predation. There is evidence that conservation tillage or non-inversion tillage enhances natural enemies (Holland, 2004; Soane et al., 2012) although less evidence that it increases biological control. One exception is a study conducted in North-eastern Italy in which levels of aphids and natural enemies were compared in cereal crops managed using conservation or conventional tillage. Levels of natural enemies were higher using conservation tillage and aphid predation was 16% higher (Tamburini et al., 2016). Further research is still needed to determine the contribution of natural enemies, especially now that pyrethroid insecticides use is likely to increase for autumn aphid control, because they are highly toxic to the natural enemies found in the autumn (Linyphiid spiders and parasitic wasps) (Moreby et al., 2001).

Overall summary

There are a number of other factors influencing a crop's susceptibility to BYDV that could also potentially be incorporated into an IPM programme and implemented though a decision support tool. The study confirmed that aphid immigration is highest around the field edges and adjacent to taller boundaries. Provided restrictions over the use of insecticides in headlands can be accommodated and that there is no or low impact on boundary over-wintering invertebrates, then selective spraying of headlands may offer an opportunity to reduce insecticide inputs and preserve natural enemies in the remainder of the field. This may also help prevent insecticide resistance developing as this would reduce the selection pressure on the aphid population. Such an approach would need field testing for both the impact on natural enemies within- and off-crop but also on subsequent aphid level, BYDV and crop yields.

In this study the type of tillage system did not appear to affect levels of immigrating aphids but may impact on subsequent aphid survival and spread within the crop. Linked to this, the importance of the green bridge for facilitating recolonization by apterate (winged) aphids needs verification for a range of crops. Alongside this the extent to which non-inversion tillage preserves the natural enemy abundance and diversity and their subsequent role with and without a green bridge needs confirming. This will be important in the future if glyphosate is withdrawn as it is highly likely to lead to a reduction in the use of non-inversion tillage unless it can be demonstrated that enhanced levels of natural enemies attributed to non-inversion tillage can overcome the green bridge effect.

Evidence was found that the landscape composition, especially grassland could be important as a source of aphids in autumn. Further landscape studies are needed to identify the type of habitats that are providing a source of migrating aphids and the contribution each makes to the abundance of winged aphids. There would also be a need to identify the relationship between the type/proportion of habitats in the landscape and subsequent immigration if risk areas are to be identified. Grassland management may also be influential. Similarly the contribution of maize, as found in France, needs evaluating.

In this study the impact of factors that may influence subsequent aphid survival on the crop such as variety, drilling date and levels of natural enemies were not investigated but also need investigating. The initial attractiveness of the crop is determined by the plant's volatiles and leaf colour whilst the plant's tolerance of the virus will determine subsequent plant growth; these may explain why differences can occur between cultivars and between barley and wheat (Harrington et al., 1999). Tolerance to BYDV in barley (e.g. YD2 gene) and wheat (Bdv2 gene) were identified in the 1960s (Kosova et al. 2008) but the development of effective seed treatments meant there has been no uptake until now. Two winter barley varieties with the YD2 gene, Rafaela, bred by Limagrain and KWS Amistar, were released in 2018 and 2019 respectively and a winter wheat variety (Wolverine, RAGT) will be available in 2020. Tolerance to BYDV has also been identified in oats (Foresman et al., 2016) The potential of later drilling and its subsequent impact on yield would need to be a component of any DST. However, for some regions (e.g. south-west England) the soil type and rainfall can limit this as an option.

5.4. Recommendations on further research needed to develop field specific monitoring and a decision support tool

Decision Support Tool

The survey conducted as part of this project showed that there is a high potential for adoption of a farm-based tool which will integrate other risk factors with current and refined practices, such as the use of weather data and monitoring at field and wider scales.

The literature review identified two previous model and decision support tools developed in the UK, which could provide a suitable basis for a new support service. Yet, work needs to be carried out to ascertain the potential to adopt/adapt these systems as well as refining and further testing the field monitoring by means of sticky traps and confirming the possibility of estimating yield losses. These previous models were complex and tried to take into account a multitude of factors relating to field- and regional characteristics, yet relatively few were influential and it may be possible to devise less complex models or refine the existing ones (M007 and M008).

The field trials of sticky traps showed that there is considerable variation in the numbers of immigrating winged cereal aphids both within and between fields, even on the same farm and that it is partly driven by the surrounding boundary type and the proportion of grassland in the surrounding landscape (800 m radius was tested). This and the feedback from the farmers involved in the trials suggests that there is an appetite for a farm/field-based monitoring system. The survey also identified that the "ideal" approach was a decision support tool that should consider weather factors, threshold based on field observations, and information related to the aphids such as presence of virus and resistance status to insecticide. The support should also provide information on the impact of drilling date, variety choice and cultivation options. This could be based upon the use of a trapping system and/or on crop inspections to assess aphid levels.

Key recommendations are:

1. Existing decision support tool: verify the availability of the full documentation and/or code of entries M007 and M008.
2. Monitoring system: verify the efficacy of yellow sticky trap to provide the input of the initial magnitude of migrant aphids.
3. Output:
    a. verify the potential of relating number of aphids caught to number colonising plants and ultimately to the number of BYDV infected plants and expected yield loss;
    b. ascertain the relative risk associated to landscape composition and cultivation practices.

Field specific monitoring

In this study the majority of fields were sown with insecticide treated seed and aphid levels were very low precluding testing with farmers whether plant counts or the use of sticky traps provided the most accurate and robust aphid assessment system. Now that neonicotinoid seed dressings aren't allowed it would be easier to test the two approaches together. Aphids are easier to identify on crops, however, this and other studies (Harrington et al., 1999) found that accuracy varied with light levels and leaf wetness. On the other hand, the sticky trap system would require improved training materials to increase accuracy. The farmer study also showed that farmers and agronomists may find it difficult to identify aphids on sticky traps without appropriate training. In addition, there was considerable by-catch of flies that caused some confusion. Yellow sticky traps were chosen because they are known to be attractive to aphids, but are also attractive to other insects. Alternative options include white traps (already manufactured by Oecos Ltd) or clear ones. These alternatives are likely to have a lower by-catch but need to be compared with yellow traps and the use of plant counts.

At its most basic, a field-based monitoring system can provide an indication of when aphids are colonising the crop and so can be used to trigger use of T-sum for timing any insecticide applications. A more advanced system would involve either the use of a DST or identification of a robust economic threshold. There is no current field-based economic threshold or economic injury level to determine whether insecticide treatments are necessary for winter cereals, as developed for a number of other crop pests. The Economic injury level (EIL) is the smallest number of pests (or injury) that will cause yield losses equal to the pest management costs whilst the Economic threshold is the density of a pest (or level of injury) at which control measures should be initiated to prevent an increasing pest population from reaching the EIL. Chemical interventions are therefore dictated by the latter, but both will vary from year to year according to the cost of inputs and crop values. The efficiency of using an Economic threshold can also be improved by using a sequential sampling approach using the cumulative number of pests found until the threshold is reached, saving monitoring effort. To determine the economic threshold, it is first necessary to identify the nature of the relationship between aphid infestation levels, visual symptoms and yields in order to generate a damage curve. Depending on the strength of the relationships, this may be between levels of winged aphids on sticky traps or aphids observed on the crop and the yield response. The proportion of winged aphids carrying BYDV may also need to be considered. Overall a relatively small proportion of aphids carry the virus (typical range found by Kendall et al. (1992) was 1-10%, although this can be higher). In this study, 5% of aphids from one field were infected whereas none had the virus in another field only two miles away. However, the French model (Fabre et al. 2003) found that use of autumn infection levels of bird cherry-oat aphid alone predicted yield loss caused by BYDV with the model having 74-91% accuracy. Use of the model reduced insecticide usage by 36%. These authors concluded that although the accuracy of the model may be improved with knowledge of BYDV infectivity in aphids, because the virus rather than aphid feeding was the main cause of damage, this was not needed. This is because the cost of potential damage is more than four times the cost of treatment therefore a highly sensitive (cautious) method is needed and assessing aphids alone will achieve this. This would result in more insecticides being applied than necessary but would reduce the risk for farmers. If virus infection levels are to be considered, further research is needed to identify why such variation in aphid infectivity occurs. There is for example, still uncertainty over the level of interaction from semi-natural habitats with the crop for both virus and vectors and the scale of such interactions, whether it is local or regional. Virus transmission rates between plant host and aphid varies between host and aphid species and between years (Masterman et al., 1994).

In this study, there was little evidence that the type of tillage inhibits initial infestation by winged aphids, however, whether there is an impact post colonisation requires investigation. Such a study should also compare whether the presence of and level of a green-bridge is important, alongside comparing different drilling dates in a multi-factorial study.

In this study only infestations of winter cereals are considered yet cereal aphids may also infest crops in the spring. Identifying whether this also poses a threat needs confirmation.

Pest natural enemies

The pest natural enemies captured on the sticky traps were comprised predominantly of parasitic wasps and to a lesser extent money spiders (Linyphiidae). Other natural enemies such as carabid beetles are also active in crops during late autumn early winter but are not caught on sticky traps. Throughout the studies there was evidence that the spatial and temporal distribution of natural enemies matched that of the aphids. This would be either because they were also dispersing in the same wind currents as the aphids or that they were exhibiting a density dependent response and seeking out their aphid prey. Either mechanism would lead to the natural enemies being located in the correct time and space to contribute to aphid control. The extent to which natural enemies control aphids in the autumn is unknown. In addition, little is known as to whether their numbers can be enhanced through provision of the required resources: Shelter, Alternative prey, Floral resources and the appropriate Environment (SAFE) (see AHDB Encyclopaedia of pests and natural enemies in field crops). Once the role of the two main guilds of natural enemy (parasitic wasps and generalist predators) is known then, with knowledge of their ecology approaches to enhance, their abundance can be devised.

Key recommendations are:

1. Compare accuracy and robustness of sticky trap versus plant count monitoring systems with farmers and agronomists.

2. If sticky traps are used, produce improved training materials for aphid identification and develop improved traps, including comparing different colours.
3. Determine whether an economic threshold based upon aphid infestation levels can be identified and test its robustness in nationwide field trials, along with different monitoring systems.
4. Determine whether the type of tillage system, green bridge management and drilling date can be used as IPM tools to reduce secondary spread of aphids.
5. Identify the role of landscape composition to determine whether high risk areas can be identified, which would consequently help with varietal choice now that BYDV tolerant varieties are becoming available.
6. Test whether selective headland spraying is a viable option to reduce insecticide usage.
7. Evaluate the impact of the main natural enemy guilds on cereal aphids in the autumn.

5.5. Recommendations for farmers to improve their knowledge and approach to BYDV management

1. Ensure that all farmers are aware that their seed is no longer treated with neonicotinoid dressing and that cereal crops are at risk of infection with BYDV.
2. Increase awareness of the T-sum approach and how this can be used to best time insecticide applications.
3. Improve their aphid identification skills and how to assess their crops in conjunction with use of T-sum.
4. Increase awareness of the impact of pyrethroid insecticides in the autumn to beneficial and non-target invertebrates and the risk of resistance developing by cereal aphids.
5. Increase awareness of IPM approaches for BYDV management, including use of resistant varieties, delayed drilling and enhancement of natural enemies at farm scale through provision of required resources and judicious use of insecticides across the farm.

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