Report on the approach for implementation of ‘in- field’ comparisons of IPM strategies

Deliverable D3.7

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An EU-wide farm network demonstrating and promoting cost-effective IPM strategies

Coordination and Support Action (CSA)

01 October 2020 – 31 March 2025 (54 months)

Deliverable D3.7

Report on the approach for implementation of 'in-field' comparison of IPM strategies

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Abstract

This deliverable describes a series of 'in-field' IPM comparisons undertaken during the IPMWORKS project. Within work package 3, Farm demonstration activities, task 3.3 supported hub coaches in encouraging growers to carry out two or more strategies within the same/comparable field, comparing a conventional strategy with an IPM based strategy as part of demonstration activities. Careful design of these comparisons enabled the collection of data on pest (weed, invertebrate or disease) levels to quantify the impact of IPM strategies across arable, outdoor vegetable, soft fruit, orchard and vineyard cropping systems. IPM strategies demonstrated include intercropping, companion cropping, use of pest thresholds and decision support systems, mechanical weeding, pheromone disruption, cover cropping and use of biologicals for disease control. By collecting data from these comparisons and sharing the reports on the IPMWORKS Resource Toolbox, the benefits of IPM strategies demonstrated in this project will extend beyond those who attended individual event. This document includes the methods, results and conclusions of each 'in-field' comparison undertaken over the duration of the project. Conclusions drawn relating to the process of implementing 'in-field' comparisons and the wider implications of results are discussed.

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1. Introduction

The European Commission is supporting research and extension efforts to mainstream IPM implementation across the EU. The Horizon 2020 project, IPMWORKS (Grant number 101000339), facilitates significant reduction in the reliance of pesticides across European agriculture by establishing an EU-wide network of farmers and advisors, demonstrating and promoting cost-effective IPM strategies. Farmer to farmer knowledge exchange through dissemination activities within the network enable demonstration of successful routes to sustainably reduce reliance on pesticides, while maintaining (or even enhancing) farm profitability. Demonstration events are based on IPM practices described at the cropping and farming system level, in line with the holistic view of IPM promoted by the network. Additionally, comparisons of alternative IPM strategies are conducted at the field level. 'In-field' comparisons facilitate demonstration of one or more IPM strategies within the context of the wider challenges of crop production. By comparing different strategies carried out in the same locations, it is possible to demonstrate impacts at small spatial scales, under the same conditions. This approach provides an excellent platform for the demonstration of IPM strategies in the local area, giving neighbouring growers and advisors the confidence that this approach will also work on their farm. Collecting data from these comparisons can provide further evidence supporting the use of a holistic IPM strategy and enable promotion to a wide network of people, further increasing uptake of IPM.

2. Overview of 'In-field' comparisons

At the start of the project, ADAS produced guidelines for 'in-field' comparisons of alternative IPM strategies for demonstration purposes (milestone 3.1)[1], which was shared with hub coaches and discussed in sector meetings to encourage uptake of this optional task. The IPM strategy being implemented was determined through discussions between farmers and their hub coaches. 'In-field' comparisons were coordinated between hub coaches and ADAS to establish a feasible protocol, allowing for quantifiable differences in efficacy of an IPM strategy when compared to a conventional approach, which often relied on the use of chemical pesticides. In organic growing systems, the standard practice referred to the approach usually implemented by the host farmer. In some cases, multiple reduced input strategies were implemented for comparison. The comparison could then be utilised at demonstration events to discuss the benefits of the chosen strategy with event attendees. In addition, project partners also carried out some 'in-field' comparisons within their networks in collaboration with other relevant projects. Target pest abundance, and yield data where available, was collected to quantify the effect of the chosen strategies and sent to ADAS to produce summary analysis and reports. All reports are uploaded to the IPMWORKS Resource Toolbox[2] as examples of useful IPM strategies. A summary of 'in-field' comparisons can be seen in Table 1.

[1] Guidelines for demonstrating and demonstration plans; https://ipmworks.net/2023/05/29/guidelines-for-demonstration/
[2] IPMWORKS Resource Toolbox; https://ipmworks.net/toolbox/en/#/home

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Table 1: Overview of 'in-field' comparisons discussed in this deliverable

Crop sector	Country	Comparison Title	Summary
Arable	Scotland	Using a Bio-fortification strategy to control foliar disease in wheat in Scotland (Part 1)	An IPM programme integrating micronutrients, elicitors, seaweed extracts and amino acids with bio-fungicides and minimal chemical fungicides, was compared to a reference disease control strategy in winter wheat grown in Scotland. Although the IPM strategy yielded 0.75t/ha less than the reference strategy, treatment frequency index was reduced by 56%, demonstrating a promising disease control approach.
Arable	England	Using a Bio-fortification strategy to control foliar disease in wheat in England (Part 2)	A biological nutrition plan using less inorganic fertiliser, was compared to a biological nutrition plan with reduced fungicide input, and a conventional fungicide and nutrition programme in wheat. While the biological nutrition plan had a lower yield than the conventional, reducing the fungicide input had no effect on yield, suggesting there is potential to reduce fungicide inputs in low pressure scenarios.
Arable	Italy	Intercropping lentils with durum wheat to reduce weed populations	An area of lentils and an area of durum wheat were compared to an area where lentils were intercropped with durum wheat on an organic farm. Weed biomass was reduced and overall crop productivity increased by intercropping.
Arable	Scotland	Using companion cropping to reduce weeds and pest pressure in Oilseed Rape	Within the same field, a conventional oilseed rape crop was compared to an area of oilseed rape drilled with a companion crop of buckwheat and berseem clover. The use of the cover crop aided the establishment of the oilseed rape, in the absence of any fertiliser or herbicides at drilling.
Arable	Germany	Using resistant potato varieties in management of potato late blight	A late blight resistant potato variety left untreated with fungicide was compared to standard varieties receiving two fungicide applications. The disease resistant potato variety had lower late blight severity than most of the conventional varieties treated with fungicide, it also had the highest yield demonstrating the potential of varietal resistance for the control of late blight.
Arable	Sweden	Using Decision Support Systems to improve canopy disease management in arable crops.	DSS-timed treatments effectively reduced disease severity and maintained yields, generally comparable to routine growth stage-based programmes and higher than untreated wheat. In four cases, the DSS determined low disease risk, so no fungicides were applied, no disease was observed and there was no recorded yield impact. Overall, the comparisons demonstrated the efficacy of DSSs in optimizing fungicide applications, allowing farmers to make informed decisions based on the risk of disease.
Arable	England	Using a Decision Support Systems to improve Barley Yellow Dwarf Virus (BYDV) management (Part 1)	A risk-averse approach with maximum insecticide use at fixed intervals, was compared to a current IPM standard using the AHDB BYDV tool, and a holistic approach combining the DSS tool and on farm monitoring. Economic analysis showed small differences in the profit margin after accounting for number of sprays between the standard IPM and holistic approaches, but a large negative margin between these and the risk averse approach.
Arable	England	Using a Decision Support System to improve Barley Yellow Dwarf Virus (BYDV) management (Part 2)	In a winter wheat field containing a BYDV susceptible variety and other containing a resistant variety, two DSSs were consulted to assess the risk of BYDV and support decisions on whether or not insecticide treatment was required. Consultation of both DSSs guided towards a low risk of BYDV in either variety, and so no applications were made. Symptoms of BYDV were assessed and found to be very low. The use of DSSs and field monitoring allows for better BYDV risk assessment and a reduction in insecticide use in low pressure years.
Arable	Netherlands	Using a Decision Support Systems to improve Barley Yellow Dwarf Virus (BYDV) management (Part 3)	Aphid populations were monitored in two fields of winter wheat in the Netherlands and the T-sum model used to guide insecticide applications. The T-sum results for these fields was also compared to a field which was drilled slightly later to demonstrate the impact of sowing date. Although aphids were present in both fields, high rainfall prevented the application of insecticide when the T-sum was reached. This highlights the importance of integrating different control strategies to reduce BYDV risk, not just relying on chemical applications alone.
Arable	England	Using a mechanical weeder in spring barley	Use of mechanical weeding was compared to conventional weed control strategies. A simple assessment of percentage weed cover in each strategy was carried out. There were no differences in weed cover between the System Cameleon drill incorporating mechanical weeding and comb cut for weed control, and the herbicide-based strategies.

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Arable	England	Using sulphur for disease control in wheat	A field of winter wheat was cultivated using one of three strategies: plough, min-till or direct drill. Within each of these strategies, one of four disease control strategies was applied: 1) a standard application of fungicides 2) and 3) applications of sulphur in replacement of standard chemical fungicides and, 4) no fungicide treatment. There was no clear difference in septoria severity or yield between the three cultivation strategies. All three fungicide strategies reduced septoria severity and increased green leaf area and consequently yield compared to the untreated, demonstrating the potential of sulphur-based fungicides for control of septoria in wheat.
Arable	Spain	Management of slugs in winter wheat	A field was split in half, with one side being direct drilled and the other half cultivated, drilled and rolled to create a fine, consolidated seed bed to demonstrate the effect of tillage on slug populations. The INTIA warning station recommended an application of chemical bait pellets post drilling, so this was applied to the whole field to guard against yield loss. The number of slugs recorded in the refuge traps was low, however there were consistently fewer slugs where tillage had been completed.
Vineyard	Spain	Using pheromone disruption to reduce grapevine moth damage in vineyards	The use of chemical insecticides was compared to the use of pheromones for control of vine moth. The pheromones cause sexual confusion, reducing moth populations. Both strategies proved to be effective with very low levels of damage seen. The use of pheromones, however, meant that no chemical insecticides were applied, whereas two applications were required in the standard approach.
Vineyard	Greece	Using cover crops to minimise herbicide use in vineyards	Cover crops as a weed control strategy were compared to mowing, pelargonic acid application, hot foam treatment, and an untreated control. The most effective weed control strategies were the use of cover crops or hot foam. Mustard tended to be the most effective monocrop, however the combination of barley, vetch, and mustard cover crops resulted in higher biomass production and better weed control than using a solo species, highlighting the effectiveness of diversified cover crop mixtures.
Vineyard	Portugal	Using holistic approaches to manage green leafhopper in vineyards	The application of insecticide to a whole area once the threshold is reached, was to be compared to an area where only the edges of the vineyard received insecticide. However, this season the threshold was not reached and so no insecticide was applied in either strategy. This shows the benefit of monitoring pests and having a set threshold in ensuring insecticide applications are only applied where necessary.
Soft Fruits	Finland	Using biocontrol for soft fruit root diseases	Efficacy of biological fungicide LALSTOP G46 WG was demonstrated by treating raspberry plants of two different varieties at two different rates, 0.03g/plant and 0.06g/plant. These were compared to plants which were left untreated. When left untreated, 6% of Glen Ample plants and 4% of Vajolet plants showed reduced growth, this was reduced to 2% where LALSTOP G46 WG was applied at 0.03g and 0% where it was applied at 0.06g in both varieties. This suggests that LALSTOP G46 WG can aid control of raspberry root diseases at the transplanting stage.
Orchard	Italy	Using rock powder in the management Olive fly	An area where olive trees received application of rock powder was compared to where no pest control treatments were applied on three farms in 2022 and 2023. In 2022 the level of olive fly damage was low, with most olives being recorded as intact across all three farms. In 2023, pest pressure was very high, with damage seen on most of the sampled olives. Rock powder did achieve a higher number of intact olives than the control at the second assessment across all three farms, however these differences were not found to be significant.
Outdoor Vegetable	Belgium	Mulching in zucchini, a comparison between polyethylene plastic and biodegradable mulch.	An area utilising biomulch for zucchini production was compared to plastic mulch by observing the biodegradability and taking green cover measurements. There were negligible differences between the two during the comparison, suggesting that biomulch could be a useful alternative to plastic mulch.
Outdoor Vegetable	Finland	Using mechanical weeding in a crop of pod peas to reduce weed pressure	A field of pod peas was divided into two sections: 0.75ha was treated with a chemical herbicide on the 25th May, whereas 1.26ha was harrowed on the 28th June. Both areas had weed species present during the assessment, with 9 species identified in the chemically treated area. However, the harrowed area had a significantly higher presence of weeds within the crop, with 19 different weed species identified. This was due to heavy rainfall immediately after the harrow was used, meaning new weeds emerged from the soil movement. It is well known that mechanical weeding can achieve good results, this comparison has highlighted that particular attention should be paid to the conditions around the time of the weeding to ensure success.

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3. Specific 'in-field' comparisons

3.1. Arable crops

3.1.1. IPMWORKS: Using a Bio-fortification strategy to control foliar disease in wheat in Scotland (Part 1)

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Summary

Biostimulants and fertilisers, for plant vigour, together with bio-fungicides and other plant protection products, play an important role in agriculture, improving resilience and resistance against infection by fungal diseases. In this comparison, the effects of a holistic plant protection programme (IPM biofortification disease management strategy) integrating combined applications of micronutrients, elicitors for induced resistance, seaweed extracts and amino acids with bio-fungicides and minimal chemical fungicides, was compared to a reference disease control strategy in winter wheat grown in Scotland. The two strategies were applied along tramlines in a single field in 2022. Yellow rust, powdery mildew and septoria tritici were observed on eventual leaves 1-4. There was no significant difference in the prevalence of powdery mildew and the severity of the disease was low. Septoria tritici infection was also similar within each strategy. However, yellow rust symptoms on flag leaves were greater in the IPM biofortification strategy. As a result, the IPM biofortification strategy yielded 0.75t/ha less than the reference strategy. A partial cost-benefit analysis was calculated based on the direct costs of each strategy, assuming equal labour costs, and average yield produced per strategy, assuming equal grain quality. The IPM biofortification strategy produced a margin over disease control cost of around £1,584/ha, whilst reducing the treatment frequency index by 56%, whereas the reference strategy produced £1,725/ha. Some minor changes to the IPM biofortification strategy, such as earlier application of a chemical fungicide, guided by a decision support system, or use of a variety more resistant against yellow rust, has potential to reduce the difference between the two strategies at very little expense, resulting in a sustainable disease control strategy less reliant on routine prophylactic chemical applications.

Introduction

This 'in-field' comparison demonstrates an IPM biofortification strategy as part of a holistic approach to winter wheat health, its foliar disease management, and the impact on pesticide use and disease management. Biofortification is a strategy to overcome micronutrient deficiencies in soils, crops and humans through plant breeding and/or soil or foliar applications (Bouis & Saltzman 2017). The susceptibility of wheat crops to disease can be influenced by deficiencies, as micro and macro nutrients are essential for plant health and disease tolerance. Wheat is one of the most important sources of calories for humans and livestock across the globe, supplying approximately 35% of this global demand (Senapati et al. 2020). Plant pathogenic fungi infestations lead to substantial reductions in wheat yields: in 2019, it was estimated that almost 22% of global wheat yields were lost due to fungal diseases (Savary et al. 2019). Diseases such as leaf rust, fusarium head blight, Septoria tritici, stripe rust, spot blotch, tan spot and powdery mildew pose the greatest threat

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to crops (Kayim et al. 2022). The intensive use of fungicides across Europe has led to wheat fungal pathogens developing resistance to many active ingredients (Carmona et al. 2020). In addition, it is known that fungicide treatments do not always result in net economic benefits for the grower (Hardwick et al. 2001; Jarroudi et al. 2015; Djurle et al. 2018), whilst having detrimental effects on the environment, impacting non-target organisms (Berry et al. 2008; Bozdogan 2015). In order to sustainably produce food for an increasing global population, alternative methods of disease control must be used.

In the biofortification strategy, several approaches were used to improve the health of the crop and to suppress plant pathogens without being wholly reliant upon chemical fungicide inputs. Micronutrients such as Zn, Mn and Cu have essential physiological roles in plant growth and defence mechanisms (Simoglou & Dordas 2006) and there is mounting evidence that Zn, Mn and Cu fertilisation in wheat can result in increased yield and nutritional quality of grain (Yilmaz et al. 1997; Karamanos et al. 2004; Khan et al. 2010; Cakmak 2009 & Cakmak et al. 2010; Zain et al. 2015). Copper is well known as an antimicrobial and antifungal agent, but perhaps less well known are the similar properties of zinc, when applied at low concentrations, which appear to be a potential supplement or substitute to copper based biocides (Rajasekaran et al. 2016).

There are now several registered fungicide-alternative active ingredients on the market which are used to trigger the plant's own innate defence response as elicitors of induced resistance. Elicitor based products utilise the systemic acquired resistance (SAR) response, which is triggered by necrotising pathogens and certain chemicals, mediated by a salicylic acid dependent process (Daniel & Guest, 2006; Walters et al., 2011; Spoel & Dong, 2012). Induced plants may be able to compensate for increased energy and resource demands of induced resistance by increasing photosynthetic rate (Murray & Walters, 1992) and so enhancing plant fitness under abiotic stresses and nutrient supply of the full suite of elements is important to maximise photosynthetic capability.

Rate of uptake of micro and macro nutrients by crops may also be improved through the application of biostimulants. Biostimulants are biologically active chemicals which have been shown to benefit plant growth and development, increasing yield and tolerance to stress (Yakhin et al. 2017). The most commonly used biostimulants are derived from seaweed extracts as crude extracts or more refined components rich in amino acids and peptides and polysaccharides (Mohammed et al. 2022). Since the introduction of Regulation (EU) 2019/1009, biostimulants within the EU must adhere to quality assurance standards. But there is no regulation of biostimulants in the UK, where this comparison took place, and their efficacy does not need to be tested before reaching the market. Therefore, the effectiveness of products varies and should be trialled by farmers before integration in IPM strategies.

The aim of this IPMWORKS comparison was to demonstrate the use of a biofortification strategy as part of integrated management of wheat diseases on an arable farm in Scotland. To make this demonstration, the IPM biofortification strategy was compared with a reference strategy approach the farmer would usually apply, and data was collected to determine the effectiveness of each approach in managing priority wheat diseases, and the wider productivity and economic implications of the two strategies. The two treatments were both on winter wheat: 1) IPM biofortification disease management strategy: Applications of bio-fungicide, foliar nutrition and biostimulants, with reduced fungicide applications, and 2) Reference strategy: a reference fungicide strategy for disease suppression throughout the growing season reflecting the farmer's usual practice.

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Results

Disease control

There was no significant difference in winter wheat infection from septoria or powdery mildew between the two treatment strategies in May (table 3.1.1.1). However, percentage cover of yellow rust was significantly higher on eventual leaf 3 (EL3) (W= 605, p=0.011) and EL4 (W=677.7, p<0.001) leaf layers of the wheat in the biofortification strategy treatment compared to standard farm practice. In June, percentage cover of EL2 leaves with septoria symptoms was significantly higher in the IPM biofortification strategy with median values of 12.5% compared to 10% in the reference treatment strategy (W=585.5, p=0.03). The percentage cover of flag leaves with yellow rust symptoms was also significantly higher in the IPM biofortification strategy compared to the reference treatment strategy with median values of 15% and 5% respectively (W=798, p<0.001). Though disease prevalence for all other leaf layers was not significantly different (Table 3.1.1.2).

For most of the season, there were few noticeable differences in NDVI between strategies (Figure 3.1.1.1). However, on the 16th July 2022 the NDVI image indicates that the IPM biofortification strategy senesced slightly earlier than the reference treatment strategy tramlines.

Table 3.1.2.1: Median percentage leaf cover by symptoms of septoria tritici, yellow rust and powdery mildew on four winter wheat leaf layers assessed on the 27th May 2022 and the inter-quartile range (IQR). Winter wheat was treated with an IPM biofortification strategy, involving a combination of biostimulants, micronutrients and the reduced use of commercial fungicides, or a reference treatment strategy. An asterisk indicates significant differences between treatment strategies as indicated by 95% confidence limits.

Leaf layer	Disease	Leaf cover by disease symptoms (%)			
		Reference treatment		IPM biofortification strategy	
		Median	IQR	Median	IQR
Flag	Septoria tritici	0	0	0	0
	Yellow rust	0	0	0	0
	Powdery mildew	0	0	0	0
EL2	Septoria tritici	0	0	0	0
	Yellow rust	0	0	0	0
	Powdery mildew	0	0	0	0
EL3	Septoria tritici	0	0	0	0
	Yellow rust*	0	1.5	2	5
	Powdery mildew	0	0	0	0
EL4	Septoria tritici	5	3	5	6.75
	Yellow rust*	0	0	2	5
	Powdery mildew	0	0	0	0

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Table 3.1.1.2: Median percentage leaf cover by symptoms of septoria tritici, yellow rust and powdery mildew on four winter wheat leaf layers assessed on the 28th June 2022 and the interquartile range (IQR). Winter wheat was treated with an IPM biofortification strategy, involving a combination of biostimulants, micronutrients and the reduced use of commercial fungicides, or a reference treatment strategy. An asterisk indicates significant differences between treatment strategies as indicated by 95% confidence limits.

Leaf layer	Disease	Leaf cover by disease symptoms (%)			
		Reference treatment		IPM biofortification strategy	
		Median	IQR	Median	IQR
Flag	Septoria tritici	5	0	5	2.15
	Yellow rust*	5	5	15	15
	Powdery mildew	0	0	0	0
EL2	Septoria tritici*	10	3.75	12.5	15
	Yellow rust	5	5	10	5
	Powdery mildew	0	0	0	0
EL3	Septoria tritici	50	23.75	50	25
	Yellow rust	25	15	10	15
	Powdery mildew	0	0	0	0
EL4	Septoria tritici	75	25	75	25
	Yellow rust	25	18.75	25	18.75
	Powdery mildew	0	0	0	0

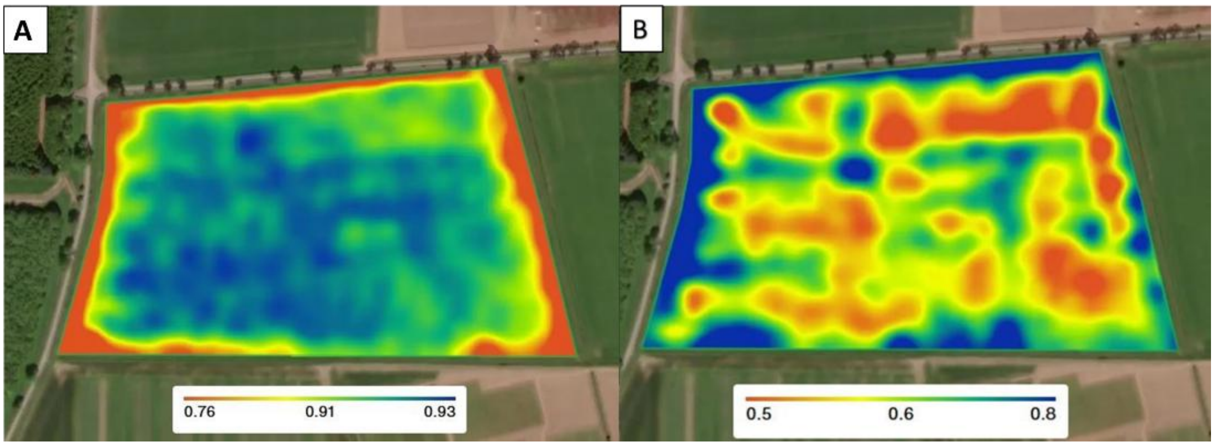

Figure 3.1.1.1: Satellite normalized difference vegetation index (NDVI) images observed A, 19th May 2022 and B, 16th July 2022 during a winter wheat comparison demonstration. Image B indicates earlier senescence by wheat treated with the IPM biofortification strategy, as shown by red coloration in the tramlines. Images accessed via www.datafarming.com.au.

Yield

The average measured yield of the reference treatment strategy was 7.14t/ha for the areas retained in the yield map analysis (Figure 3.1.1.2). The IPM biofortification strategy resulted in a reduction in yield of 0.75 ± 0.42 t/ha (95% confidence interval) in comparison to the reference treatment strategy and the difference was unlikely to have been caused by unexplained variation in yield across the field (P<0.001).

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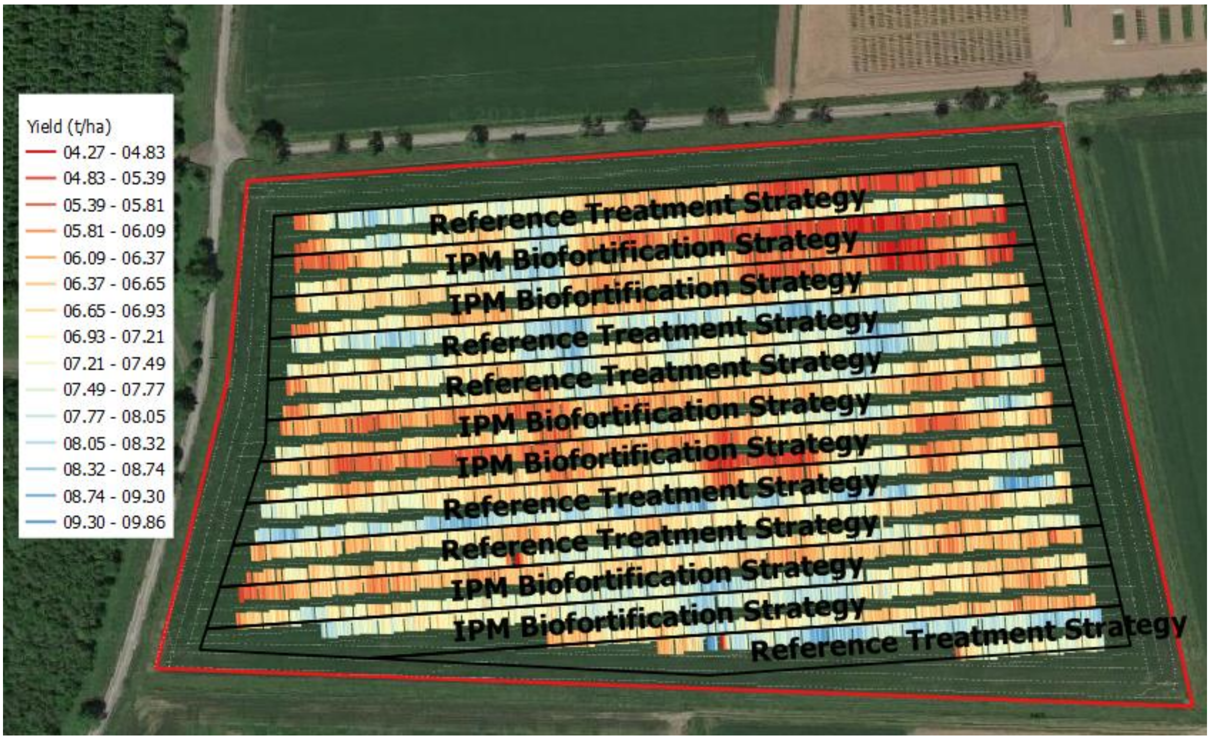

Figure 3.1.1.2: Yield map produced by an R Shiny graphical user interface (GUI) indicating differences within and between tramlines of winter wheat treated with an IPM biofortification strategy, involving a combination of biostimulants, micronutrients and the reduced use of commercial fungicides alternated with a reference treatment strategy. Methods described further in Marchant et al. (2019).

Economic Analysis

The total cost for all products in the reference treatment strategy was equal to £152.79/ha whereas the biofortification strategy cost £96.27/ha, a difference of £56.52/ha (Figure 3.1.1.3). Using a grain price of £263/t, to return the same margin over disease control cost as the reference treatment strategy, a yield reduction in proportion to the reduced input costs would equal 0.21 t/ha, assuming all other costs in each strategy were equal (equation 1). The biofortification strategy yielded 0.75 ± 0.42 t/ha less than the reference treatment strategy. Based on the same grain price, this equates to an approximate margin of £1,584 /ha, whereas, the reference treatment produced an approximate margin over disease control cost of £1,725/ha (equation 2).

Figure 3.1.1.2 Total costs (£/ha) for all pesticide applications of the reference treatment strategy (orange) and the IPM biofortification strategy (green).

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The TFI for the IPM biofortification and reference treatment strategies were 2.34 and 5.36 respectively, demonstrating a 56% reduction in all fungicide applications, including the bio-fungicides applied within the IPM biofortification strategy. This includes Thiopron and Iodus, which are organic compliant non-synthetic chemical fungicides. Removing these from the TFI calculation for the IPM biofortification strategy reduces the TFI to 1.29, an overall reduction of 76% in synthetic chemical fungicide applications.

Conclusions

In this comparison, the IPM biofortification strategy, utilising foliar nutrition, bio-fungicides, biostimulants and minimal chemical fungicide inputs resulted in similar levels of septoria tritici and powdery mildew infection to the reference treatment strategy, while reducing the TFI by 56% and reducing the cost of disease control. However, wheat under the biofortification strategy was susceptible to yellow rust, resulting in a yield decrease of 0.75t/ha compared to the reference treatment. The difference between margin over disease control costs was small, a promising result given the large reduction in chemical fungicides. Further investigation into the integration of other IPM approaches, such as DSS, should be conducted to determine disease pressure and inform the timing of interventions for improved disease management without increasing fungicide inputs, increasing productivity and profit margins while transitioning towards minimal pesticide inputs.

Methods

A field site was located approximately 8 miles northwest of Dundee, Scotland in a crop of winter wheat (cv. Skyscraper). Variation in vegetative growth across the field was examined using normalized difference vegetation index (NDVI) images. As the tramline width was only 18m and combine header 6m, each strategy block was two tramlines wide to provide a larger area to take yield from. The IPM biofortification disease management strategy and reference treatment blocks were alternated across the field, providing replication, to enable robust statistical analysis of the data (Figure 3.1.1.4).

Figure 3.1.1.3 Demonstration design, comparing an IPM biofortification strategy alongside a reference treatment strategy. Black lines show tramline wheeling's.

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IPM Biofortification strategy

The biofortification strategy incorporated elicitors of induced resistance applied at T0 using laminarin and phosphite/PGA products, to stimulate defence responses before disease infection occurred. The latter also aimed to stimulate root growth during early development. At T1, the start of the yield forming phase of development through stem extension, biostimulants with amino acids, a seaweed-based product and foliar nutrition was applied aiming to improve plant fitness at first node. A registered sulphur-based fungicide was also applied at T1, and T2 to provide an antifungal effect. To maintain plant fitness, retain flag leaf area and maximise photosynthetic capacity at T2, the seaweed-based product was applied, as well as a biostimulant, which claims to boost chlorophyll production. A product containing Zn and Cu micronutrients was also applied at T2 to reduce the effect of micronutrient deficiencies at peak biomass, and to provide a biocidal antifungal effect on pathogens present on the flag leaf. The biofortification strategy was based on plant physiology, with an aim to trigger the plants’ innate defence response early in the programme, and direct energy and resources toward grain fill rather than defence response in the later stages of development. Thus, the T3 ear spray, required to protect grain quality, reverted to the use of conventional fungicides and matched the reference treatment. Selection and design of the IPM Biofortification strategy was done in collaboration between the farmer, their advisor, the IPMWORKS Hub Coach, and project researchers.

Reference treatment strategy

This strategy followed the host farm’s usual plant protection programme with alternating modes of action applied. This included; a multi-site fungicide plus mildew eradicant at T0 (2-4 weeks prior to leaf 3 emergence). Once leaf 3 had emerged, at T1 (BBCH31-33), a multi-site fungicide plus an azole and succinate dehydrogenase inhibitor (SDHI) were applied as a prophylactic application against septoria tritici and yellow rust. At T2, once the flag leaf had emerged (BBCH39) a multi-site fungicide plus an azole and SDHI were applied to extend protection to the flag leaf. Finally, at T3 (BBCH59), an azole was applied as an ear wash to protect against sooty moulds and fusarium spp. plus strobilurin to combat yellow rust infections.

Disease and yield assessments

Assessments were made to quantify any differences in disease prevalence between the two strategies. On the 27th May and 28th June 2022, disease was assessed at 30 randomly spaced points within each strategy across the field (5 per tramline), at least 25 m from the headland wheeling, spaced at least 10 m apart, and at least 0.5 m from the wheeling the assessor walked along. At each assessment point, randomly selected tillers were assessed for disease by leaf layer, for the top four leaves. Leaves were designated EL1 (flag leaf), EL2, EL3 and EL4. Percentage cover for each disease was estimated based on symptoms characteristically associated with each infection. The winter wheat was harvested on the 12th August 2022. The whole field was harvested with the same combine harvester on the same date.

Data analysis

Disease prevalence data analysis

Differences between disease prevalence (as percentage leaf cover) for each strategy were analysed using R Statistical Software (v4.2.2; R Core Team 2021). Percentage cover for each disease observed on each leaf layer were compared by Wilcoxon rank-sum tests. Data collected on different assessment dates were analysed separately.

Yield data analysis

Yield map data was analysed using an R Shiny graphical user interface (GUI) according to the detailed methods described by Marchant et al. (2019). Raw yield data were corrected to 15% moisture content and

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cleaned to eliminate systematic and random errors. These errors are identified by manual and automatic filtering, removing miscalculations in yield due to the combine running over areas that have already been harvested, changes in speed of harvest across the tramline, harvest rows where the swath width was less than a full header width etc. Rows of data points were straightened to refine the coarse geo-referencing quality provided by the harvester. Following this, a time shift was applied to account for the delay between the crop being cut and the grain yield being recorded by the monitor (Muhammed et al., 2014).

The differences in yield between the two strategies was investigated by applying a linear mixed model, accounting for spatial variation across rows and along rows. The modelled strategy effect with standard error of the difference (SED) provides the size of the strategy difference after excluding the effects of modelled underlying variation (Roques et al. 2022). Without access to the novel analysis software used here, comparisons between strategies could be conducted using a weighbridge. This would require calculating average yield per tramline, avoiding harvesting across the strategy boundary.

Economic analysis

An economic analysis was conducted based on direct input costs of the products in each strategy and the average grain price available at the time of evaluation. A so-called partial cost-benefit analysis of IPM-related inputs and operations was provided. The reason for limiting the analysis to IPM-related inputs and operations was to highlight the costs and benefits of advanced pest and disease management strategies. Taking into consideration stock of inputs and operations that are identical in standard and holistic management strategies was not considered useful. An equivalent yield loss (t/ha) was calculated by determining the difference in direct costs between strategies as a proportion of the grain price value, as shown in equation 1. This value indicates the level of reduced yield that would equal the same margin over disease control cost, as a result of the reduced input costs.

$$\text{Equivalent yield loss (t/ha)} = \frac{\text{Cost of standard practice (£/ha)} - \text{Cost of alternative strategy (£/ha)}}{\text{Grain price (£/t)}}$$

Equation 1

Approximate margin over disease control costs were calculated based on the average yield achieved and the cost of disease control products in each strategy using equation 2, assuming an average grain price of £263/t (UK average grain price reported by AHDB between January and September 2022; AHDB 2023), and excluding any other related costs.

$$\text{Margin over disease control cost (£)} = [\text{Average yield (t/ha)} \times \text{Average grain price (£/t)}] - \text{Direct cost of disease control strategy (£/ha)}$$

Equation 2

Treatment frequency index (TFI) was also determined by calculating the proportion of the full label rate that each pesticide product was used at (including Thiopron and Iodus) and summing the result for each product within each strategy, as shown in Equation 3. The percentage reduction in TFI between the reference treatment strategy and IPM biofortification strategy was then calculated.

$$TFI = \sum \frac{Application\ Rate\ (L/_{ha})}{Registered\ Dose\ (L/_{ha})}$$

Equation 3

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Table 3.1.1.3: Product descriptions and cost breakdown for the IPM biofortification disease management strategy and reference treatment strategy.

Stage	Reference treatment strategy				IPM biofortification strategy			
	Product	MAPP	Application rate (L/ha)	Cost (£/ha)	Active ingredient	MAPP	Application rate (L/ha)	Cost (£/ha)
T0 (28/03/22)	Phoenix (Folpet 500g/L)	15259	1	9.14	Iodus (Laminarin 37g/L)	19163	0.75	8.33
	Vegas (Cyflufenamid 50g/L)	15238	0.15	14.97	Nutri-phite PGA (3% N, 26% P_2O_5, 7% K_2O, 0.5% Mn, 0.5% Zn)	N/A	0.5	7.40
T1 (27/04/22)	Phoenix (Folpet 500g/L) Proline 275 (Prothioconazole 275g/L) Entargo (Boscalid 500g/L)	15259 14790 19312	1 0.2 0.6	9.14 9.70 15.60	Zonda (Amino acid biostimulant) Maxicrop Triple (Seaweed biostimulant - 3.1% N, 1.4% P, 2.9% K plus trace elements) Mitra (Foliar nutrition Mn + S) Thiopron (Sulphur 825g/L)	N/A N/A N/A 19147	0.5 1 2 1.5	5.50 3.62 8.48 7.22
T2 (02/06/22)	Revystar XE (Fluxapyroxad 47.5g/L, mefentrifluconazole 100g/L) Phoenix (Folpet 500g/L)	19250 15259	1 1	50.90 9.14	Zynergy (2.11% Cu, 3.75% Zn, 7.4% S) Maxicrop Triple (Seaweed biostimulant - 3.1% N, 1.4% P, 2.9% K plus trace elements) Klorofill (Chlorophyll 0.04mg/L) Thiopron (Sulphur 825g/L)	NA NA NA 19147	0.25 1 1 1.5	2.33 3.93 8.06 7.22
T3 (16/06/22)	Cleancrop Teboo (Tebuconazole 250g/L) Tucana (Pyraclostrobin 250g/L)	18111 10899	0.75 0.65	9.65 24.54	Cleancrop Teboo (Tebuconazole 250g/L) Tucana (Pyraclastrobin 250g/L)	18111 10899	0.75 0.65	9.65 24.54

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3.1.2. IPMWORKS: Using a Bio-fortification strategy to control foliar disease in wheat in England (Part 2)

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Summary

Biofertilisers have recently gained prominence to increase fertiliser efficiency and reduce intensive application of nitrogen-based fertilisers. Derived from beneficial microorganisms, biofertilisers may contribute to soil fertility, enhance nutrient availability, and foster plant growth. This approach promotes healthier crops and mitigates the adverse impacts associated with excessive chemical fertiliser use but also has implications for plant resilience against pests and diseases. In this comparison, three strategies for crop nutrition and disease control were compared in winter wheat grown in England. Strategies were applied along tramlines in a single field in 2022. One strategy, the biological nutrition plan, integrated the use of microbial based fertilisers and the reduced application of nitrogen. The second strategy, a reduced fungicide biological nutrition plan, followed the same approach as previously mentioned but also received a reduced input fungicide programme. Both approaches were compared to a conventional fungicide and nutrition strategy. Septoria tritici and green leaf area were observed on eventual leaves 1 and 2 in July. Septoria tritici infection was similar within the conventional strategy and biological nutrition plan. Septoria symptoms on leaf 1 were greater in the biological nutrition plan with reduced fungicide application. However, septoria severity was low across all strategies (<7%). Green leaf area on leaf 1 was lower for the biological nutrition plan with reduced fungicide application but did not differ significantly between the standard farm strategy and the biological nutrition plan with the same number of fungicide applications. The average measured yield of the biological nutrition plan was 10.8 t/ha. The standard farm practice yielded 0.81 t/ha ± 0.46 t/ha more than the biological nutrition plan. Reducing the fungicide application within the biological nutrition plan had little effect on yield, reducing by 0.05 t/ha ± 0.79 t/ha. The findings underscore the complexity of balancing disease management and crop productivity within the realm of biofortification strategies, calling for ongoing research and fine-tuning to unlock the full potential of biofertilisers in achieving sustainable and resilient agricultural practices. This comparison was carried out in collaboration with LEAF (Linking Environment and Farming).

Introduction

All cereal crops require nitrogen to produce a canopy capable of photosynthesis as well as for storage proteins in the grain. Growth, yield and quality depend on substantial nitrogen inputs (Hawkesford 2014). Whilst the addition of nitrogen in agricultural systems results in increased productivity, the detrimental effects encompassing harm to crops and forests due to ozone-induced injury, acidification, over-enrichment (eutrophication) of aquatic ecosystems, biodiversity decline, haze impairing visibility, and the broader issue of global climate change are all recognized as adverse impacts (Ribaudo et al. 2011).

Wheat is one of the most important sources of calories for humans and livestock across the globe, supplying approximately 35% of this global demand (Senapati et al. 2020). Plant pathogenic fungi infestations lead to substantial reductions in wheat yields: in 2019, it was estimated that almost 22% of global wheat yields were lost due to fungal diseases (Savary et al. 2019). Diseases such as leaf rust, fusarium head blight, septoria tritici, stripe rust, spot blotch, tan spot and powdery mildew pose the greatest threat to wheat crops in Europe (Kayim et al. 2022). The intensive use of fungicides across Europe has led to wheat fungal pathogens developing resistance to many active ingredients (Carmona et al. 2020). In addition, it is known that fungicide

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treatments do not always result in net economic benefits for the grower (Hardwick et al. 2001; Jarroudi et al. 2015; Djurle et al. 2018), whilst having detrimental effects on the environment, impacting non-target organisms (Berry et al. 2008; Bozdogan 2015). To sustainably produce food for an increasing global population, alternative methods of disease control and nitrogen use efficiency must be established.

This 'in-field' comparison demonstrates an IPM biological nutrition strategy as part of a holistic approach to winter wheat health, its foliar disease management, and the impact on fertiliser and pesticide use, and disease management. In this comparison, three products were applied to improve the health of the crop and to suppress plant pathogens whilst increasing nitrogen use efficiency and reducing nitrogen input. BioStart was applied to the seed, containing *Penicillium Bilaiae*, it enhances seed germination, promotes seedling growth and improves nutrient uptake. Bio-N is a foliar application, containing nitrogen fixing bacteria (*Bacillus subtilis*) to convert atmospheric nitrogen and N from organic matter into readily available ammonium for the crop. Another foliar product, MegaPhos containing the bacterium *Bacillus megaterium* was applied and solubilises the phosphorous in the soil, making it readily available to the plant, increasing plant growth and promoting activity against plant pathogens (Kildea et al. 2008). These products are biostimulants. Biostimulants are biologically active chemicals which have been shown to benefit plant growth and development, increasing yield and tolerance to stress (Yakhin et al. 2017). Since the introduction of Regulation (EU) 2019/1009, biostimulants within the EU must adhere to quality assurance standards. However, there is currently no regulation of biostimulants in the UK, where this comparison took place, and their efficacy does not yet need to be tested before reaching the market. Therefore, the effectiveness of products varies and should be trialled by farmers before integration into IPM strategies.

The aim of this comparison was to demonstrate the use of a biological nutrition strategy as part of integrated management of wheat diseases on an arable farm in Cambridge in 2022, carried out in collaboration with LEAF. The IPM biological nutrition strategy was compared with a reference strategy the farmer would usually apply in winter wheat, plus another strategy following the biological nutrition plan which also had reduced fungicide input. Data was collected to determine the effectiveness of each approach in managing priority wheat diseases, and the productivity implications of the three strategies. The three strategies were: 1) Biological nutrition strategy: applications of a bio-fungicide, foliar nutrition and biostimulants 2) Biological nutrition strategy – Reduced fungicide: applications of bio-fungicide, foliar nutrition and biostimulants, with reduced fungicide input, and 3) Reference strategy: a reference nutrient and fungicide strategy for disease suppression throughout the growing season reflecting the farmer's standard practice.

Results

Disease control

The only foliar disease recorded in the field was septoria. Across both eventual leaf 1 and 2, the average septoria severity recorded in all strategies was very low with less than 2%. This is not surprising given that the variety Extase was used, which is naturally resistant to foliar disease. There was a significant difference in septoria severity between the strategies on eventual leaf 1 (Table 3.1.2.1; $F_{2,20}$=4.23, p=0.029), where the standard farm practice significantly reduced septoria severity below that of the biological nutrition plan – reduced fungicide strategy. Green leaf area was also significantly different between strategies for leaf 1 ($F_{2,26}$=7.98, p=0.0019) and leaf 2 ($F_{2,45}$= 3.212, p=0.049) with the reference, standard farm practice showing greater green leaf area than the biological nutrition plan with reduced fungicide application.

Percentage cover of leaf 1 and leaf 2 with septoria symptoms and green leaf area did not significantly differ between the standard farm practice and the biological nutrition plan (with the same fungicide applications).

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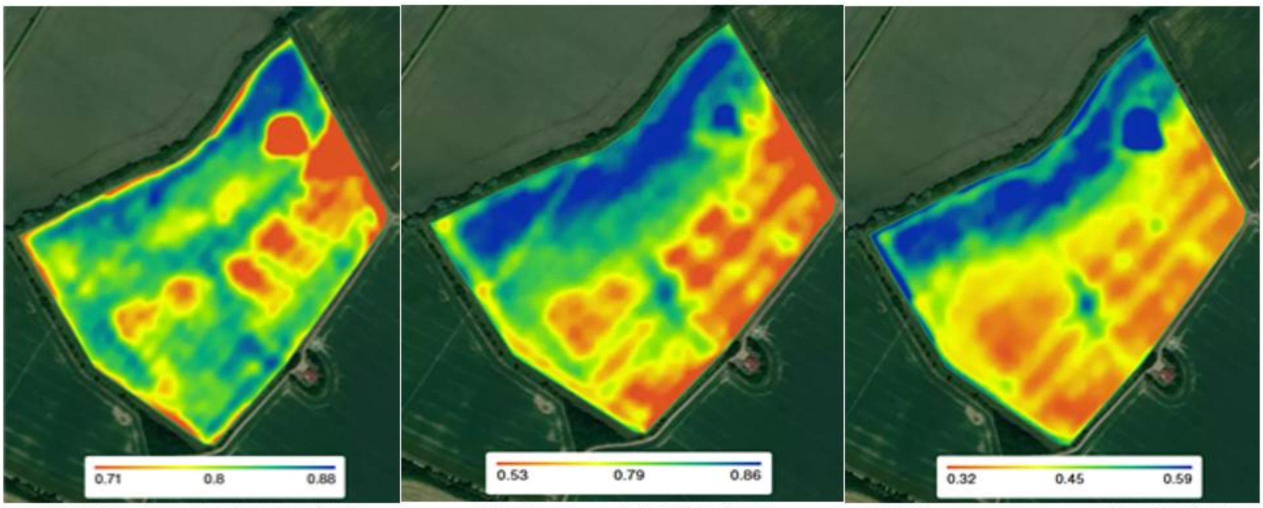
Table 3.1.2.1: Percentage coverage of eventual leaf 1 with septoria tritici symptoms and green leaf area during assessments conducted within three nutrition and fungicide strategies of winter wheat in the same field in Cambridge, UK, 01/07/2022. Significant differences were determined for strategies followed by a different letter by Analysis of variance and the Tukey test.

	Biological Nutrition Plan	Biological Nutrition Plan - Reduced Fungicide	Standard Farm Practice
Leaf 1 Septoria (%)	0.28 ± 0.74 ab	1.57 ± 2.32 a	0.031 ± 0.13 b
Leaf 1 GLA (%)	69.6 ± 21.6 ab	65.9 ± 20.3 a	85.7 ± 10.2 b

Table 3.1.2.2: Percentage coverage of eventual leaf 2 with septoria tritici symptoms and green leaf area during assessments conducted within three nutrition and fungicide strategies of winter wheat in the same field in Cambridge, UK, 01/07/2022. Significant differences were determined for strategies followed by a different letter by Analysis of variance and the Tukey test.

	Biological Nutrition Plan	Biological Nutrition Plan - Reduced Fungicide	Standard Farm Practice
Leaf 2 Septoria (%)	0.64± 1.65 a	1.66 ± 3.54 a	0.35 ± 1.12 a
Leaf 2 GLA (%)	54.8± 29 ab	45.1 ± 27.6 a	68.2 ± 20.5 b

NDVI images are often able to pick up differences in green leaf area between different strategies. When comparing the field plan with NDVI images, the two tramlines which received the reference, standard farm practice, stand out as having a higher NDVI value, as shown in figure 1 on the 25th June and 10th July (Figure 3.1.2.1). The crop would have been senescing in July, so it is likely that the standard farm practice senesced slightly later than the biological nutrition plan.



NDVI before T0 (25/02/22) NDVI after T2 (25/06/22) NDVI at senescence (10/07/22)

Figure 3.1.2.1: Normalized difference vegetation index (NDVI) of winter wheat field used in a biological nutrition comparison near Cambridge, England at three key stages of the comparison: before T0, after T2 and at crop senescence. Imaged sourced from https://www.datafarming.com.au/.

Yield

The average measured yield of the farm biological nutrition plan was 10.8 t/ha, according to yield map data. This is likely to be a little higher than the true average due the exclusion of headlands and wheelings from the analysis. Using the Agronomics analysis to fit a statistical model to the data (Marchant et al. 2019)., we estimate that the reference, standard farm practice increased yield by 0.81 t/ha ± 0.46 t/ha (95% confidence interval), relative to the biological nutrition plan. Measured yield values do vary across a field even when the

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same strategy is applied everywhere, but the bounds of the confidence intervals indicate that, according to the underlying statistical model, the estimated yield loss from the biological nutrition plan was unlikely to have been the result of this unexplained variation. It is likely that an increase in tiller survival, and therefore greater ears per m^2, contributed to this increase in yield by the standard farm approach, as an ear count completed on the 1st July found an average of 640 ears per m^2 in the stand, compared to 598 ears per m^2 in the biological nutrition plan.

Reducing the fungicide application within the biological nutrition plan had little effect on yield, reducing by 0.05 t/ha ± 0.79 t/ha (95% confidence interval). This variation is not likely to be due to the strategy, indicating that it is possible to maintain yield with a lesser fungicide programme when a biological nutrition plan is followed. In the future, it may also be beneficial to test whether a reduced fungicide programme in a standard nutrition plan maintained a similar yield.

Economic Analysis

The total spend on nutrition and fungicide products in the reference, standard farm practice was £335/ha (table 3.1.2.3, table 3.1.2.4). Although the cost of nitrogen was reduced by £127/ha in the biological nutrition plan compared to the reference, the additional nutritional products totalled £117/ha, representing a saving of £10. Due to the difference in yield, the margin over fungicide and nutrition cost was slightly higher for the reference strategy at £2,405/ha compared to £2,224/ha in the biological nutrition plan, based on an average grain price of £236/ha.

The fungicide programme used in both the reference treatment and the biological nutrition strategy cost a total of £81/ha. Reducing fungicide input at T2 in the biological nutrition plan with reduced fungicide, reduced the cost to £49/ha. As the yield was very similar in both strategies under the biological nutrition plan, the reduction of fungicide input resulted in an increased margin of £2,256, compared to £2,223.

Conclusions

In this case, the 50% reduction in synthetic fertilisers in the biological nutrition plan resulted in a yield loss of 0.81t/ha compared to a standard fungicide programme. However, the biological nutrition plan still achieved a good yield of 10.8t/ha. It is anecdotally known that bio-fungicides, biostimultants and foliar nutrition products have potential to aid the reduction of reliance on synthetic fertilisers. If a slightly more modest reduction in fertiliser had been used, the biological nutrition plan may have achieved a similar yield and margin to the standard farm practice.

Use of a variety such as Extase, which boasts strong resistance to foliar disease, allows for a greater level of foliar disease management and flexibility in fungicide programmes. In this comparison, removing the SDHI (Succinate dehydrogenase inhibitors) based product of the fungicide programme at T2 (GS39) in the biological nutrition plan, resulted in no significant change in disease severity, no impact on yield and a slight increase in the margin. Many crops receive more fungicides than required due to the unpredictable nature of disease outbreaks. Robust fungicide programs are often considered a safeguard against yield loss from disease outbreaks. To bolster growers' confidence in reducing fungicide usage where disease risk is low, decision support systems (DSS) should be utilised. There is already a septoria DSS available on the IPM Decisions platform, that was developed in Denmark. Combining growers knowledge of their crops, and disease epidemics with disease models, growers should be able to refine fungicide programmes to ensure fungicides are only applied where required and at appropriate doses for the disease risk.

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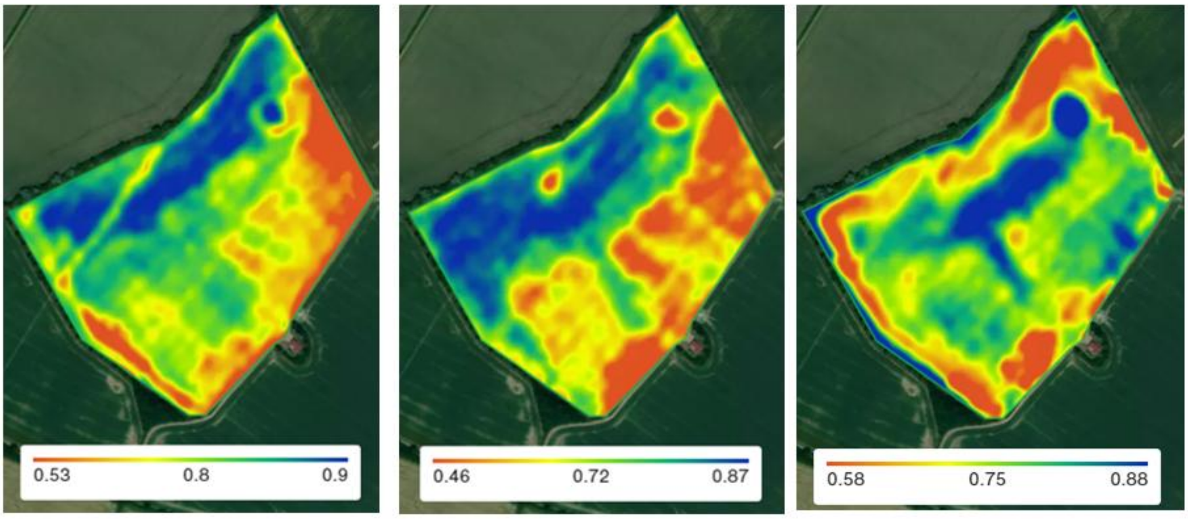
Methods

A field site was located near Cambridge, England in a crop of winter wheat. The variety Extase was used, due to its high resistance ratings against foliar disease, rated 7 for mildew, 8 for yellow rust, 7 for brown rust and 8 for septoria, on a 1 to 9 scale where 9 is resistant (AHDB recommended list 2021-2022). Variation in vegetative growth across the field was examined using normalized difference vegetation index (NDVI) images. Prior to the comparison starting the field showed variation in NDVI, along a SW to NE line (Figure 3.1.2.2). The IPM biofortification disease management strategies and reference standard farm practice blocks were alternated across one half of the field, providing replication in parts of the field with similar NDVI results, to enable robust statistical analysis of the data (Figure 3.1.2.3).



25th June 2020 27th December 2020 31st May 2021

Figure 3.1.2.2: Normalized difference vegetation index (NDVI) of winter wheat field used in a biological nutrition comparison near Cambridge, England prior to the comparison taking place. Images sourced from https://www.datafarming.com.au/.

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Figure 3.1.2.3. Demonstration design, comparing an IPM biological nutrition strategy and biological nutrition strategy with reduced fungicide application alongside a reference strategy (standard farm practice). Black lines show tramline wheeling's.

Reference strategy

The reference strategy followed standard farm practice, with a total nitrogen rate of 218kg N/ha.

A nitrogen fertiliser application of 50 kg N/ha was applied in February, followed by two further applications of 84 kg N/ha. To control disease, an azole was applied at T0, followed by an SDHI based product applied as a prophylactic application against septoria tritici and yellow rust once leaf 3 had emerged at T1. At T2, once eventual leaf 1 had emerged (BBCH39) a second SDHI based application and a strobilurin was applied. Finally, at T3 (BBCH59), an azole was applied as an ear wash to protect against sooty moulds and fusarium spp. All details are shown in Table 3.1.2.3.

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IPM Biofortification strategy

The IPM biological nutrition strategy included a seed treatment of BioStart, and foliar applications of MegaPhos SP and Bio N. MegaPhos SP contains *Bacillus megaterium* strain HM87. In theory, use of MegaPhos SP will release bound up phosphorous in the soil thereby increasing fertilizer efficiency, eliminating the need to over apply nutrients. Bio N is a microbial based fertiliser mainly composed of bacteria that can convert atmospheric nitrogen (N_2) into a form that is usable by the crop, enhancing shoot growth and root development. Synthetic nitrogen was applied at 50kg N/ha in February and another 60kg N/ha in March, totalling 110kg N/ha. The same fungicide programme was applied as the standard farm practice. The fungicide programme used was quite low input, however to see whether inputs could be reduced further in the biological nutrition plan, one of the tramlines did not receive the SDHI based product at T2.

Disease, ear count and yield assessments

An assessment of disease severity and green leaf area was made to quantify any differences in disease prevalence between the strategies. On the 1st July 2022, disease was assessed at 16 randomly spaced points within each strategy, at least 25 m from the headland wheeling, spaced at least 10 m apart, and at least 0.5 m from the wheeling the assessor walked along. At each assessment point, the crop was parted, and the percentage leaf area infected with disease, and remaining green leaf area was estimated on the top two leaves (eventual leaf 1 and 2). Percentage cover for disease was estimated based on symptoms characteristically associated with infection. An ear count was also completed by placing a 0.5m stick between drill rows and counting the number of ears on both sides of the stick. This was converted to ears per m^2. The field was harvested on the 20th July. The whole field was harvested with the same combine harvester on the same date, with a header width of 7.5m and tramline width of 24m, three swaths were cut per tramline, with the middle one centred on the wheelings and the combine header full throughout.

Data analysis

Disease prevalence data analysis

Differences between disease prevalence (as percentage leaf cover) for each strategy were analysed by Analysis of variance and the Tukey test using R Statistical Software (v4.2.2; R Core Team 2021).

Yield data analysis

Yield map data was analysed using an R Shiny graphical user interface (GUI) according to the detailed methods described by Marchant et al. (2019). Raw yield data were corrected to 15% moisture content and cleaned to eliminate systematic and random errors. These errors are identified by manual and automatic filtering, removing miscalculations in yield due to the combine running over areas that have already been harvested, changes in speed of harvest across the tramline, harvest rows where the swath width was less than a full header width etc. Rows of data points were straightened to refine the coarse geo-referencing quality provided by the harvester. Following this, a time shift was applied to account for the delay between the crop being cut and the grain yield being recorded by the monitor (Muhammed et al., 2014).

The differences in yield between the three strategies was investigated by applying a linear mixed model, accounting for spatial variation across rows and along rows. The modelled strategy effect with standard error of the difference (SED) provides the size of the strategy difference after excluding the effects of modelled underlying variation (Roques et al. 2022). Without access to the novel analysis software used here, comparisons between strategies could be conducted using a weighbridge. This would require calculating average yield per tramline, avoiding harvesting across the strategy boundary.

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Table 3.1.2.3: Product descriptions and cost breakdown for the IPM biological nutrition strategy, biological nutrition strategy with reduced fungicide application and a reference strategy in the winter wheat comparison.

Stage	**Reference: Standard farm practice**			**IPM biological nutrition strategy**			**IPM biological nutrition strategy with reduced fungicide**		
	Active ingredient	Application rate (l/ha)	Cost (£/ha)	Active ingredient	Application rate (l/ha)	Cost (£/ha)	Active ingredient	Application rate (l/ha)	Cost (£/ha)
T0 (15/03/22)	Toledo (Tebuconazole)	0.15	£2.64	Toledo (Tebuconazole)	0.15	£2.64	Toledo (Tebuconazole)	0.15	£2.64
T1 (20/04/22)	Ascra Xpro (Bixafen + Fluopyram + prothioconazole)	1.0	£32.00	Ascra Xpro (Bixafen + Fluopyram + prothioconazole)	1.0	£32.00	Ascra Xpro (Bixafen + Fluopyram + prothioconazole)	1.0	£32.00
T2 (14/05/22)	Ascra Xpro (Bixafen + Fluopyram + prothioconazole) Tazer (azoxystrobin)	1.0 0.3	£37.76	Ascra Xpro (Bixafen + Fluopyram + prothioconazole) Tazer (azoxystrobin)	1.0 0.3	£37.76	Tazer (azoxystrobin)	0.3	£5.76
T3 (01/06/22)	Toledo (Tebuconazole)	0.5	£8.60	Toledo (Tebuconazole)	0.5	£8.60	Toledo (Tebuconazole)	0.5	£8.60
Total Fungicide Spend	£81.00			£81.00			£49.00		

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Table 3.1.2.4. Nutrient applications for the IPM biological nutrition strategy, biological nutrition strategy with reduced fungicide application and a reference strategy in the winter wheat comparison.

Date	Reference: Standard farm practice	IPM biological nutrition strategy	IPM biological nutrition strategy with reduced fungicide
Pre-drilling 28/02/22	 50 kg N/ha	BioStart 50 kg N/ha	BioStart 50 kg N/ha
14/03/22		Mega Phos	Mega Phos
29/03/22	84 kg N/ha	60 kg N/ha	60 kg N/ha
05/04/22		BIO N	BIO N
12/04/22	84 kg N/ha		
03/05/22		BIO N	BIO N
Total N:	218 kg N/ha	110 kg N/ha	110 kg N/ha
Total Cost of Nutrition: (£/ha)	£254	£244	£244

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3.1.3. IPMWORKS: Using intercropping of lentils with durum wheat to reduce weed populations in Italy

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Summary

Weed control in crops of lentils can be difficult, particularly in organic systems. Lentils are relatively poor competitors, and so weeds can quickly hamper establishment and early growth of the lentil crop. Intercropping, a system in which two or more crops grow simultaneously in the same field, has been shown to help with weed control in crops of lentils by increasing competition. Within the same field an area of lentils and an area of durum wheat were compared to an area where lentils were intercropped with durum wheat on a certified organic farm in Italy. An assessment of weeds was completed in each area on the 15th March 2023, at which time lentil grown alone, already had visibly higher weed presence. Weed and crop biomass assessments were then carried out at harvest showing that weed biomass was reduced and overall crop productivity increased by intercropping lentils with durum wheat.

Introduction

One of the biggest challenges of growing lentils is weed control. The short, thin structure of lentil plants means that lentil is a poor competitor against weeds. Crops with a high proportion of weeds will yield less and be more difficult to harvest. It is therefore vital to take an integrated approach to weed control, combining preventative measures, cultural measures and where permitted effective use of herbicides (Alberta Pulse Growers, 2024). In research by Bochra et al. (2013), intercropping (IC) is defined as the simultaneous growth of two or more kinds of crops from different growth stages. Thus, achieving an increase in the productivity of the two crops with stable output and environmental sustainability. Nyoki et al. (2018) found that intercropping improves crop yields and soil fertility as well as productivity. The biodiversity introduced through intercropping can enhance soil health, promote beneficial insect populations, and contribute to a more resilient and sustainable agricultural ecosystem (Li et al., 2019; Khan et al., 2018).

Intercropping systems are important agricultural practices for increasing seed yield (Iqbal et al. 2018). Recent studies from Koskey, G. et al. (2022) revealed that intercropping significantly increased grain yield compared to monocropping against both monocrops in 2021 and non-significantly against durum wheat in 2019 and 2020. Yield advantage in both intercropping systems ranged between 164 and 648%. Equally Leoni et al. (2023) found that wheat-lentil intercrops sown at 150 kg/ha provided a higher production than sole crops and significantly improved weed control. The key mechanism underlying this success lies in the increased competition for resources, such as sunlight, nutrients, and water, between the lentil plants and the companion crops. The benefits of intercropping legumes with cereals are maximised in low-input or organic systems where the absence or the extremely reduced use of external inputs, leads to a greater weed population and lower nutrient levels. The use of fertiliser can promote growth of the wheat crop, increasing its competitiveness against the lentils (Leoni et al. 2022). The practicalities of drilling and optimising seed rates and harvest also have to be considered to make the most of growing two crops (Leoni et al. 2023).

In this comparison, an area of a field was drilled with both durum wheat and lentils, referred to herein as mixed crop, and compared to a separate area within the same field of wheat and lentil grown alone on a certified organic farm in the Province of Pisa, Italy in 2023. This demonstration aimed to explore the benefits of intercropping for weed control in lentil crops.

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Results

The emergence assessment on the 02 December 2022 found a higher number of durum wheat and lentil plants where grown on their own compared to the mixed crop, however differences were not statistically significant (Table 3.1.3.1, Table 3.1.3.2). This is as expected as the number of seeds of each crop would have been higher where drilled as a solo than in the mixture and there is less competition in the monocrops. When grown on its own, the durum wheat had a significantly lower percentage weed cover on the 15 March 2023 than the mixed crop, at 8% compared to 18%. There were fewer *Anagallis arvensis* and *Anthemis arvensis* plants in the Durum wheat crop, but more *Phalaris paradoxa* and *Sinapis arvensis* than the mixture. The lentil crop had a higher percentage of weed cover than the mixed crop, although this wasn't quite statistically significant (P=0.06). However, the plant counts of weed species were similar for most species and slightly higher in the mixed crop for *Sinapis arvensis, Anagallis arvensis* and *Anthemis arvensis.*

Areas of the crop were destructively sampled at harvest and taken back to the lab for analysis. The total dry weight of weeds was lower in the mixed crop compared to the durum wheat crop, however this difference was not statistically significant (Table 3.1.3.3). Total durum wheat fresh weight biomass, fresh weight and dry weight of the ears and the dry weight of the grains was significantly higher in the mixed crop than where the durum wheat had been grown on its own. This is consistent with observations that the durum wheat in the mixed crop was visibly healthier, suggesting that intercropping with lentils supported the growth of the durum wheat.

The mixed crop had significantly lower weed biomass dry weight than the lentil only crop, suggesting that intercropping lentil with durum wheat helped to increase crop competition against weeds (Table 3.1.3.4). The total dry weight of lentil biomass, residues and grains was significantly lower where lentil had been grown in the mixed crop, compared to being grown on its own. This is because 50% fewer lentil seeds were drilled in the mixture compared to the solo crop. However, by intercropping two valuable grains in the same area, overall crop productivity is increased, achieving a combined dry weight of 182g/m^2 compared to either 100g/m^2 of wheat alone or 49g/m^2 of lentil alone.

Table 3.1.3.1: Emergence of wheat in both the wheat only and mixed area on the 2^nd^ December and the percentage coverage of wheat, lentil and weeds, with a breakdown of weed species per m^2 on the 15^th^ March. Data analysed using Student T-Test.

Date of assessment	Assessment	Durum Wheat Only	Mixed	Two-sample T-test P Value
02/12/2022	Emergence of Durum wheat (plants/m^2)	125	114	0.35
15/03/2023	Wheat Coverage (%)	25	30	0.05
	Lentil Coverage (%)	0	12	-
	Weed Coverage (%)	8	18	**0.02**
	Bare Soil (%)	67	40	**<0.01**
	Phalaris paradoxa (Canary grass) plants/m^2	83	45	**0.01**
	Lolium spp. (Ryegrass) plants/m^2	6	3	0.33
	Sinapis arvensis (Charlock) plants/m^2	73	30	**0.01**
	Anagallis arvensis (Scarlet pimpernel) plants/m^2	24	51	0.06
	Anthemis arvensis (Chamomile) plants/m^2	0	65	**0.02**
	Galium aparine (Cleavers) plants/m^2	0	0	0.33
	Ranunculus arvensis (Buttercup) plants/m^2	0	0	-
	Trifolium alexandrinum (Berseem clover) plants/m^2	0	1	0.31
	Kickxia elatine (Sharp-leaved fluellen) plants/m^2	0	0	0.33
	Ammi maius (Bishop's flower) plants/m^2	1	1	0.57
	Helminthotheca echioides (Prickly oxtongue) plants/m^2	0	1	0.57

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Table 3.1.3.2: Emergence of lentil in both the lentil only and mixed area on the 2nd December and the percentage coverage of wheat, lentil and weeds, with a breakdown of weed species per m² on the 15th March. Data analysed using Student T-Test.

Date of assessment	Assessment	Lentil Only	Mixed	Two-sample T-test P Value
02/12/2022	Emergence of Lentils (plants/m²)	91	72	0.13
15/03/2023	Wheat Coverage (%)	0	30	-
	Lentil Coverage (%)	26	12	**<0.01**
	Weed Coverage (%)	28	18	**0.06**
	Bare Soil (%)	46	40	0.21
	Phalaris paradoxa (Canary grass) plants/m²	44	45	0.96
	Lolium spp. (Ryegrass) plants/m²	2	3	0.10
	Sinapis arvensis (Charlock) plants/m²	11	30	0.10
	Anagallis arvensis (Scarlet pimpernel) plants/m²	34	51	0.19
	Anthemis arvensis (Chamomile) plants/m²	17	65	0.08
	Galium aparine (Cleavers) plants/m²	1	0	0.06
	Ranunculus arvensis (Buttercup) plants/m²	1	0	0.14
	Trifolium alexandrinum (Berseem clover) plants/m²	2	1	0.13
	Kickxia elatine (Sharp-leaved fluellen) plants/m²	0	0	0.92
	Ammi maius (Bishop's flower) plants/m²	1	1	0.45
	Helminthotheca echioides (Prickly oxtongue) plants/m²	0	1	0.33

Table 3.1.3.3: Fresh weight (FW) and Dry Weight (DW) of the weeds, durum wheat and lentils in the durum wheat and mixed crops on the 26th June 2023. Data analysed using Student T-Test.

Harvest values per m²	Durum Wheat Only	Mixed	Two-sample T-test P Value
Total DW weeds (g)	232	202	0.58
Total FW wheat biomass (g)	355	610	**<0.01**
FW wheat straw sample (g)	137	161	0.29
DW wheat straw sample (g)	123	145	0.28
Number of wheat ears	205	247	0.33
FW wheat ears (g)	178	289	**0.01**
DW wheat ears (g)	159	253	**0.02**
Total DW wheat grains (g)	100	157	**0.04**
Total DW lentil biomass (g)	0	67	-
Total DW lentil residues (g)	0	42	-
Total DW lentil grains (g)	0	25	-

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Table 3.1.3.4: Fresh weight (FW) and Dry Weight (DW) of the durum wheat and lentils in the lentils and mixed crops on the 26th June 2023. Data analysed using Student T-Test.

Harvest values per m2	Lentil Only	Mixed	Two-sample T-test P Value
Total DW weeds (g)	336	202	**<0.01**
Total FW wheat biomass (g)	0	610	-
FW wheat straw sample (g)	0	161	-
DW wheat straw sample (g)	0	145	-
Number of wheat ears	0	247	-
FW wheat ears (g)	0	289	-
DW wheat ears (g)	0	253	-
Total DW wheat grains (g)	0	157	-
Total DW lentil biomass (g)	126	67	**0.02**
Total DW lentil residues (g)	77	42	**0.03**
Total DW lentil grains (g)	49	25	**0.01**

Conclusions

This comparison has indicated that intercropping lentils with durum wheat can help to reduce weed burden on an organic farm, with a significant reduction in weed biomass achieved at harvest compared to lentil grown alone. The durum wheat yield in the mixed area exceeded that of the durum wheat grown alone and overall productivity in the mixed area was higher than either crop grown as a monocrop. This result is supported in the wider literature with similar success stories of this IPM strategy. While there are some practical considerations to consider such as drilling and harvesting complications with an intercrop and balancing the seed rates to optimise weed control and yield. This strategy shows great potential in low input systems and incorporation into lentil production alongside other preventative and cultural control measures such as crop rotation, good crop hygiene, mechanical weeding and high seed rates in a holistic management strategy will help to increase overall crop production, while also providing more biodiversity, promoting soil health and invertebrate populations.

Methods

Strategies

This comparison was designed to investigate whether intercropping with durum wheat could improve weed control in lentils on a certified organic farm. The three strategies were all drilled on the 31st October 2022. The lentil only area was drilled at a rate of 95kg/ha, in the mixed area, durum wheat was added to the tank at a weight proportion of 50% wheat and 50% lentils and mixed by hand in the tank before drilling at 95kg/ha. The durum wheat area was then drilled at 250kg/ha.

Table 3.1.3.5: Three strategies demonstrated in this comparison

Strategy 1:	Crop of lentils
Strategy 2:	Crop of durum wheat
Strategy 3:	Crop of lentils, intercropped with durum wheat

Satellite Imagery

Prior to starting the comparison, NDVI images were examined to check the consistency of the field. NDVI (normalized difference vegetation index) is a spectral reflectance index which shows a combination of canopy size and greenness, on a scale from 0 to 1. Satellite NDVI images were sourced from

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www.datafarming.com.au to show underlying variation in the field. The colour scale varies between images, but always runs from red (low) through orange, yellow and green to blue (high).

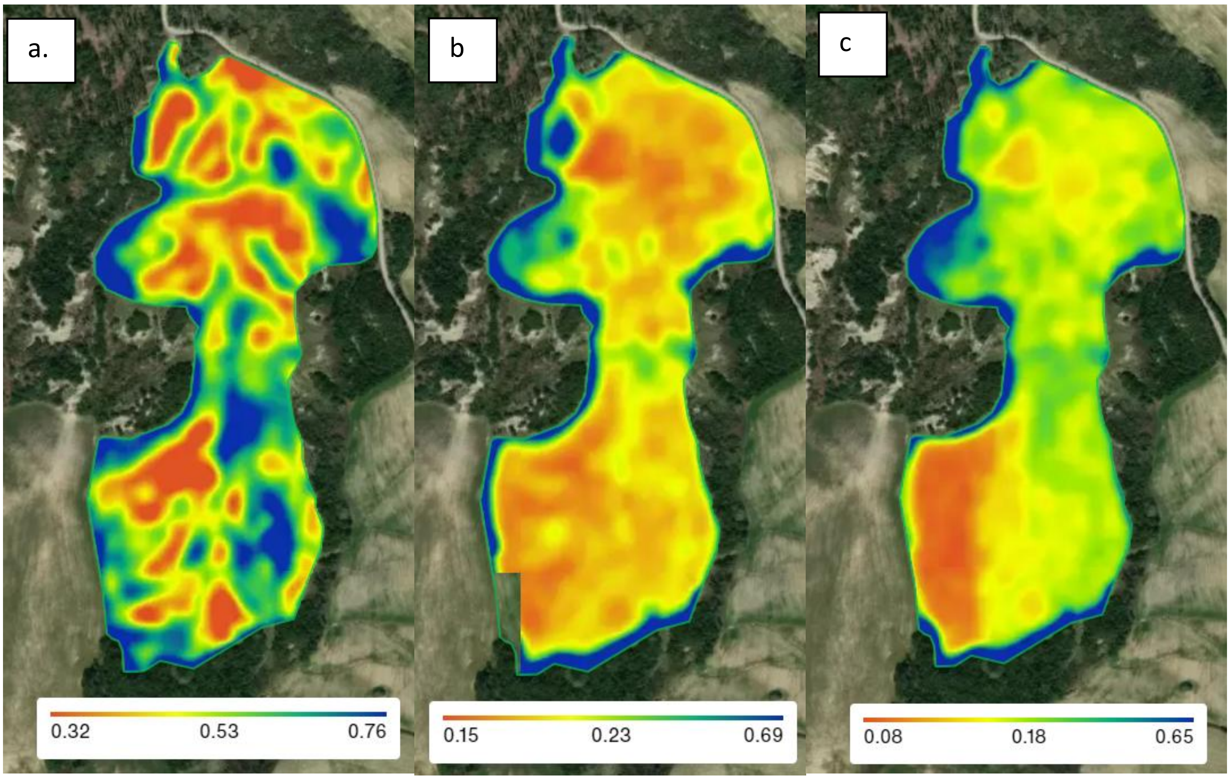

Figure 3.1.3.1: NDVI images of the field from the a. 18th April 2022, b. 2nd June 2022 and c. 7th July 2022 sourced from https://maps.datafarming.com.

Figure 3.1.3.2: Image of the 'in-field' comparison layout

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Design

NDVI images show that there was some natural variation in the field given its location. The three areas for comparison were therefore kept close together, within the same part of the field.

Establishment Assessment

The number of durum wheat and lentil plants were counted in at least 5, 1m^2 areas within each strategy once the crop had fully emerged.

Weed Counts

In at least 5, 1m^2 areas within each strategy, percentage cover of weed species was estimated and the number of plants of each species present counted.

Yield

In at least 5, 1m^2 areas within each strategy, all above ground material was removed and placed into a bag, keeping each sample separate, taken back to the lab. Each sample was divided into weed material, durum wheat and lentils then further divided the durum wheat into straw and grain and lentils into grain and lentil residue, weighing each group. Samples were put in the oven to dry to 100% dry matter, before reweighing each group.

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3.1.4. IPMWORKS: Using companion cropping to reduce weeds and pest pressure in Oilseed Rape in Scotland

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Summary

Companion cropping of oilseed rape has many benefits. Companion crops can attract specialist and generalist predators of cabbage stem flea beetle (CSFB), as well as disguising the oilseed rape crop by masking the plant volatiles that oilseed rape produces, which can reduce CSFB infestations. Weed burden can be reduced through increased competition. The use of legumes within the companion plant mix can fix nitrogen which will be released when the companion crop is destroyed. The root systems can help with drainage and soil structure. It's also been reported that there is less pigeon grazing where cover crops are used. An 'in-field' comparison was completed in oilseed rape (OSR) located outside of Dundee, Scotland. Within the same field, a strip of oilseed rape was drilled down the centre of the field and an area of oilseed rape with a companion crop of buckwheat and berseem clover was drilled on either side. The oilseed rape only area received a pre-emergence herbicide application and fertiliser to the seedbed. Each area was monitored frequently for cabbage stem flea beetle using yellow water traps, and a leaf area loss assessment was completed on the 15th September. A weed count was completed in each area on the 15th September and 24th January and crop biomass assessments completed on the 19th December and 20th February. Slugs were the most prevalent pest, however the oilseed rape within the companion cropping area had less damage to the leaf area than the oilseed rape grown alone. Possibly because the slugs were also feeding on the companion plants. Crop biomass also tended to be slightly higher when grown with a companion crop. Yield data was collected by harvesting a 125m by 6m strip within each area, which yielded 333kg for the OSR only section and 332kg where established with the companion crop (4.4t/ha). Therefore, companion cropping of oilseed rape can help to aid establishment of oilseed rape crops, in the absence of pre-emergence herbicides and fertiliser applications at drilling, bringing added pest and weed control benefits.

Introduction

Globally, Winter Oilseed Rape (WOSR) is cultivated on approximately 35 billion hectares of land. From 2007 to 2017 there was substantial increase in the arable land dedicated to WOSR, reaching 5 billion hectares (FAO, 2024), driven by the growing demand for vegetable oil (Flénet *et al*, 2020). Given WOSR's elevated nitrogen requirements and sensitivity to weed growth, incorporating companion crops during late summer planting is recommended to address these challenges. Companion crops, when sown with WOSR, enhance soil coverage, serving as living mulch to suppress weeds (Verret *et al,* 2017). "Using the correct companion crop or blend of crops has clear agronomic benefits when trying to establish a new crop of oilseed rape." (ProCam, 2023). Utilizing plant mixtures to enhance crop productivity and pest control can mitigate the environmental impact of agriculture by minimizing the use of pesticides and fertilisers.

Amidst the challenges posed by pest management, researchers and farmers are increasingly turning to companion cropping as an innovative and sustainable strategy to enhance the performance of winter oilseed rape. Companion cropping has shown promise in promoting natural enemy populations that act as biological control agents, reducing the incidence of pests on winter oilseed rape. This integrated pest management approach minimizes the need for synthetic pesticides, fostering sustainable and environmentally friendly agricultural practices (Cook, & Khan, 2007). Certain companion crops, strategically chosen for intercropping with winter oilseed rape, contribute to improved nutrient utilization and soil health. By diversifying plant

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species in the field, companion crops enhance nutrient cycling and mitigate the risk of nutrient imbalances, ultimately promoting healthier oilseed rape plants (Ryan & Estefan 2001). Companion cropping can play a pivotal role in weed suppression through resource competition. The strategic selection of companion crops creates a dense canopy that hinders weed growth, reducing competition for nutrients, water, and sunlight with the winter oilseed rape, resulting in improved crop yields (Bàrberi, 2002). Experimental data gathered over different years and locations demonstrated that both legume and non-legume companion plants resulted in a substantial reduction in weed density (52% and 38%, respectively) (Verret *et al*, 2017). Research suggests that specific companion plant combinations reduced weed abundance by up to 75% in WOSR without resorting to herbicides (Lorin *et al*, 2015). Companion cropping contributes to increased biodiversity within agricultural landscapes. This ecological diversification enhances the resilience of the agroecosystem, making it more adaptable to environmental changes and disturbances, thereby promoting long-term sustainability (Tscharntke *et al*., 2012). Companion cropping has demonstrated its potential in enhancing the climate resilience and adaptability of winter oilseed rape. Research suggests that specific companion crops can provide resilience against adverse weather conditions, optimizing overall crop performance (Zargar, *et al.*, 2017).

This comparison utilised buckwheat and berseem clover which offer multiple advantages to OSR, including providing a beneficial canopy for the root system and assisting in phosphate scavenging (Bayer Crop Science, 2022). Buckwheat, with its adaptability to a wide range of climatic conditions, serves as a valuable companion crop in oilseed rape systems. Its resilience to adverse weather conditions contributes to climate adaptation, providing stability to the overall cropping system (Ahmed *et al*., 2019). Legumes, such as berseem clover, are known for nitrogen-fixing abilities, can enhance soil fertility by converting atmospheric nitrogen into a form accessible to plants. This biological nitrogen fixation not only benefits the berseem clover itself but also provides an additional nitrogen source for the oilseed rape, reducing the need for synthetic fertilizers (Jensen & Hauggaard-Nielsen, 2003). Research proposes intercropping with companion crops allowed for a notable reduction in nitrogen applications without a significant decrease in rapeseed yield (Verret *et al*, 2017). Companion crops like buckwheat and berseem clover have demonstrated the ability to repel certain pests or attract natural enemies, contributing to a reduction in pest pressure on oilseed rape. Both buckwheat and berseem clover are also killed by a frost over the winter, allowing non-chemical destruction of the cover crop to prevent competition against the OSR crop later in the season. This integrated pest management approach helps mitigate the need for chemical interventions, promoting a more sustainable farming system (Hauggaard-Nielsen *et al*., 2008). Instances of insect/pest damage were found to be lower in intercrop treatments compared to sole WOSR treatments (Cadoux *et al*. 2015).

An 'in-field' comparison was completed in oilseed rape (OSR) located outside of Dundee, Scotland in the autumn of 2022. The objective of this demonstration was to assess how planting companion crops alongside OSR could mitigate weed and pest challenges while enhancing crop establishment. Two strategies were employed: Strategy 1 involved the cultivation of OSR alone, utilizing NP autumn fertilizer (30kg N/ha) and a pre-emergence herbicide containing 3 active ingredients (dimethenamid, metazachlor and quinmerac). Strategy 2 involved planting OSR with companion crops, omitting pre-emergence herbicides and fertilisers during sowing. A post emergence herbicide was applied to the whole field on the 10th December, by which point the frost had already killed most of the companion crop.

Results

Table 3.1.4.1 presents comparative data on the performance of winter oilseed rape (OSR) grown with and without a companion crop. OSR grown alongside companion crops exhibited a significantly lower leaf area loss, registering at 3.80%, compared to OSR grown alone, which recorded a higher leaf area loss of 10.18%. The leaf area loss was thought to be due to slugs. This difference in grazing between the two strategies may be due to the slugs concurrently consuming both the companion crops and OSR, whereas in the OSR only

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area, they only had OSR to graze. Additionally, crops grown with companion crops displayed a slight increase in biomass and significant increase in plant establishment.

On September 15th, companion crops had a slightly higher weed count compared to OSR alone, consistent with expectations as the companion crops had not been treated with a pre-emergence herbicide (Table 3.1.4.2). The second weed count was completed on January 24th after a herbicide had been applied to the whole field on the 10th December and as such showed similar populations for both crops, except for annual meadow grass (AMG) and forget me not, which was significantly higher in the companion crop. Notably, there were no instances of AMG in the OSR alone on both dates.

Table 3.1.4.1: Plant establishment, leaf area loss and biomass in the OSR only area compared to the OSR grown with a companion crop. Data analysed by a paired T-test.

	OSR Only	OSR with Companion Crop	Paired T-Test P Value
Establishment (Plants/m2) – 15th September	21.60	33.33	0.002
Leaf area loss per plant (%)– 15th September	10.18	3.80	<0.001
Biomass - 19th December	0.78	0.82	0.741
Biomass - 20th February	0.38	0.44	0.315

Table 3.1.4.2: Weed species counted in the OSR only area, compared to the OSR with a companion crop on the 15th September and 24th January.

	15th September			**24th January**		
	OSR Only (Plants/m2)	**OSR with Companion Crop (Plants/m2)**	**Paired T-test P value**	**OSR Only (Plants/m2)**	**OSR with Companion Crop (Plants/m2)**	**Paired T-test P value**
Volunteer Barley *Hordeum vulgare*	11	15	0.63	16	13	0.77
Fumitory *Fumaria officinalis*	6	3	0.47	1	0	0.34
Common Knotgrass *Polygonum aviculare*	50	27	0.15	0	1	0.34
Field Pansy *Viola arvensis*	15	23	0.38	8	8	1.00
Doves foot Cranesbill *Geranium molle*	2	11	0.45	6	10	0.56
Day Nettle *Urtica dioica*	0	1	0.34	0	0	-
Common Chickweed *Stellaria media*	0	2	0.34	0	2	0.34
Black Bindweed *Solanum nigrum*	0	14	**0.02**	0	0	-
Annual Meadow Grass *Poa annua*	0	204	**<0.001**	0	71	**<0.001**
Forget Me Not *Myosotis scorpioides*	0	0	-	0	6	**0.02**
Mayweed *Tripleurospermum spp.*	0	0	-	1	1	1.00
Groundsel *Senecio vulgaris*	0	0	-	3	0	0.08

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Yield data was collected by harvesting a 125m by 6m strip within each area, which yielded 333kg for the OSR only section and 332kg where established with the companion crop (4.4t/ha).

Economic Analysis

The cost of establishing the OSR with a companion crop was lower than the OSR only crop, as the cost of applying fertiliser to the seedbed and a herbicide to help the OSR only crop establish, was greater than the cost of the companion crop seed. Growing the companion crop enabled the grower to omit the early fertiliser and herbicide application, making a substantial saving of £155/ha (Table 3.1.4.3).

Table 3.1.4.3: Cost of establishing the OSR only crop compared to OSR with a companion crop in £/ha.

	Cost of Establishment (£/ha)	
	OSR Only	**OSR with Companion Crop**
WOSR Seed	£81	£81
Companion crop seed		£27
Fertiliser to seedbed	£126	
Herbicide	£56	
Slug Pellets	£20	£20
Total	**£283**	**£128**

Conclusions

Companion cropping as a strategy for establishing winter oilseed rape (OSR) has yielded compelling results, shedding light on the multifaceted benefits it brings to pest management, weed control, and overall crop establishment. This demonstration revealed great insights into the advantages of this integrated approach. The results indicate that companion cropping of oilseed rape can mitigate pest damage. The prevalent pest in this case was slugs, the OSR within the companion cropping area exhibited less damage to the leaf area compared to the OSR grown alone, likely due to the slugs feeding on the companion crop. The OSR grown with a companion crop also had improved establishment and slightly high biomass. Furthermore, the yield data collected revealed no difference between the two strategies. The costs of establishing the crop were also lower for the OSR with a companion, increasing the profitability of the crop, whilst reducing fertiliser and herbicide use. Companion cropping presents a strategy that not only aids in pest and weed management but also contributes to overall soil health, nutrient availability, and potential reductions in fertiliser and pesticide usage. The slightly higher weed infestation observed in the strategy with companion crop and reduced herbicide did not affect the OSR yield, but could replenish the soil seed bank, with potential consequences on the next crops, which will require special attention.

Methods

Strategies

This comparison was designed to demonstrate the effect of planting companion plants with OSR to reduce weed and pest burden and improve crop establishment.

Table 3.1.4.4: Description of each strategy, including herbicide and fertiliser applications.

	Crop	Herbicides	Fertiliser
Strategy 1:	OSR Crop (Inv1035)	Pre-emergence herbicide applied and followed up with post-emergence options if required	Sown with NP autumn fertiliser applied up to 30kgN
Strategy 2:	Buckwheat and Berseem clover sown in mixture with OSR crop (Inv1035)	No pre-emergence herbicide applied, post emergence options used once companions die back	No fertiliser at sowing

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Satellite Imagery

NDVI (normalized difference vegetation index) is a spectral reflectance index which shows a combination of canopy size and greenness, on a scale from 0 to 1. Satellite NDVI images were sourced from www.datafarming.com.au to show underlying variation in the field. The colour scale varies between images, but always runs from red (low) through orange, yellow and green to blue (high).

13th November 2021 | 23rd March 2022 | 20th April 2022

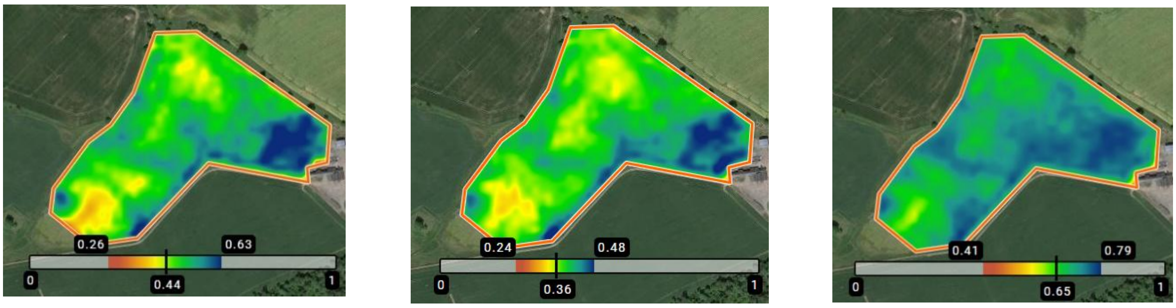

Figure 3.1.4.1: NDVI images of the field before starting the comparison. Sourced from https://maps.datafarming.com

Design

NDVI images show that the field is fairly consistent, although there is a patch of lower NDVI at the South end of the field. Four tramlines of OSR only area were drilled starting 12m from the SE fence line, working West. As fertiliser was applied by spinning disk, assessment points avoided the area between tramlines at the treatment boundary as this will not have received an even application of the fertiliser. 10 assessment points per strategy were marked in the field with canes. The points were located near the strategy boundary line in a pairwise nature. Assessment points were at least 25 m from the headland wheeling or treatment boundary, spaced at least 10 m apart, and at least 0.5 m from the wheeling's. Data for each assessment was collected from around the canes. The grey spots in the field image below show approximate positions for the 10 assessment points per strategy in a pairwise arrangement.

Figure 3.1.4.2: Field plan showing the location of the different strategies and assessment points.

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Adult Cabbage Stem Flea Beetle numbers

Numbers of adult CSFB were monitored using yellow water traps (YWTs; round, 26 cm diameter, 8.5 cm deep; Flora trap, Ringot Ltd, France). Water traps were located at least 20m into the crop and at least 1m away from any wheeling's or tramlines. Four water traps were placed in each strategy making sure they are at least 50m apart, two traps were located in four places, marked by the yellow spots in the field plan above. Each trap was filled approx. three quarters full of water and a few drops of detergent and a Campden tablet were added. Traps were set up as soon as the crop was drilled and moved out of the way during any applications. Traps were monitored weekly until the end of November. CSFB caught in the traps were counted in the field (separate counts for each trap) and traps reset.

Leaf area loss

Percentage leaf area lost caused by crop pests was assessed on 50 plants per strategy, 5 per assessment point. The plants growth stage (GS) and the pest thought to have caused the damage was also recorded. Some examples of percent leaf area lost are shown below.

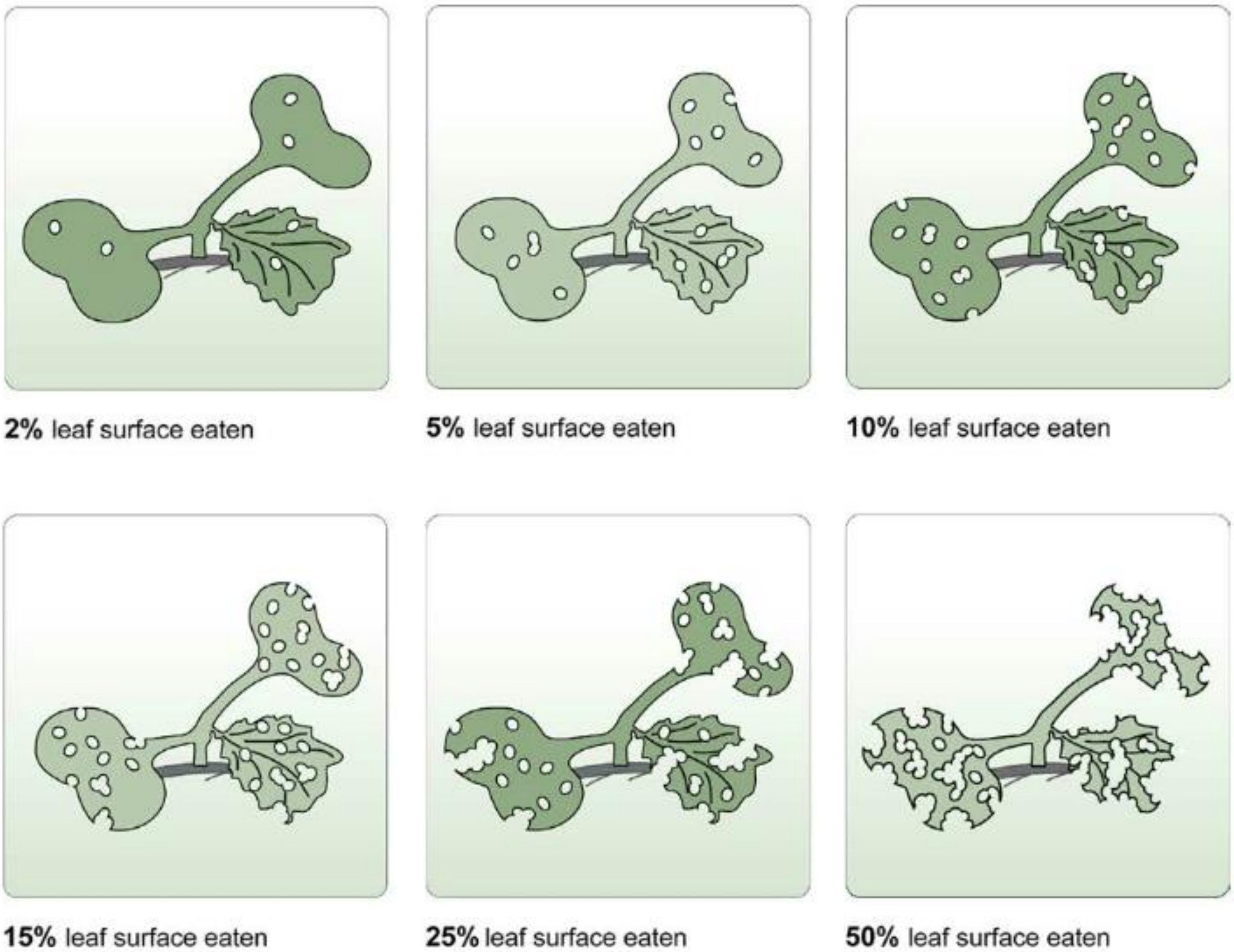

Figure 3.1.4.3: Examples of percent leaf area of oilseed rape eaten by Psylliodes chrysocephala beetles. Taken from EPPO guidance PP 1/073.

Weed Counts

2-3 weeks after crop emergence, before any post emergence graminicides using a 0.1m^2 (31.6cm x 31.6cm) quadrat, all weed species were identified and counted within the quadrat, in 10 quadrats per strategy, one per assessment point. Companion plants were not included in the count. In January, the same assessment

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points were returned to, by placing the quadrat in the same place, with the marker in the top left-hand corner and a second weed count completed.

Establishment Assessment

An establishment assessment was carried out once both strategies had emerged, at around the 2-3 true leaf stage. Emergence was assessed at 30 points per strategy, 3 per assessment point, using a 0.25m^2 quadrat, positioning the quadrat diagonally to the direction of drilling. Being careful not to include any weeds or companion plants in the count.

Biomass Assessment

A biomass assessment in December and again in February, in 10 places per strategy, one per assessment point. Each sample was collected and processed as below:

- Place a 1.0m^2 (100cm x 100cm) quadrat on the ground, positioned diagonally to the direction of drilling.
- Sample 1m^2 of crop by cutting the stems within the quadrat at ground level and remove all leaves and stems that belong to each cut stem (even if they are outside the sampled area). Place all the plant material from the quadrat in one labelled bag.
- Record the fresh weight of the whole sample.
- If the GAI is < 1 (if the crop covers less than 50% of the ground then it is likely to have a GAI of less than 1) process the whole sample, if it's > GAI 1, then use a 50% subsample by weight. Record the fresh weight of the subsample.
- Separate into green leaf area, stem area with any buds and dead material. If a leaf has more than 30% dead material, then rip off the approximate area of dead tissue.
- Feed the green leaves and green stems (with any buds) through a leaf area machine (calibrate before use) and record separate values for: 1) the green area of the leaves and 2) the green area of the stem with any buds.
- Bulk the leaf, stem and dead material into one sample (i.e. the entire subsample (green and dead)) and dry at 80^{o}C until it reaches constant dry weight. Record the dry weight.
- Use these values to calculate total dry weight per m^2 and GAI for each sampling point.

Yield

Yield was assessed using a weighbridge. An area 125m long and 6m wide was harvested in each strategy.

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3.1.5. IPMWORKS: Using resistant potato varieties in management of potato late blight in Germany

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Summary

Currently potato production relies heavily on multiple fungicide applications to control late blight. Late blight is spread by wind dispersal of spores from infected crops or volunteer potatoes onto newly emerged crops. Infection results in necrosis of leaf tissue and rotting of the tubers, reducing yield. This in-field comparison investigated the performance of a disease resistant potato variety left untreated with fungicide in comparison to standard varieties receiving two fungicide applications within a 38-hectare field in Germany in 2023. The aim of this comparison was to demonstrate that fungicide inputs could be reduced by adopting late blight resistant varieties. Disease and yield data were collected to evaluate the performance of each strategy. Left untreated with fungicide, the disease resistant potato variety had lower late blight severity than most of the conventional varieties treated with fungicide, it also had the highest yield demonstrating the potential of varietal resistance for the control of late blight.

Introduction

The potato, alongside wheat and maize, has been a cornerstone in global food and nutrition security for centuries (Pandey et al., 2005). However, late blight disease presents a significant threat to potato production. Caused by the oomycete pathogen *Phytophthora infestans*, it is one of the most destructive diseases affecting potato crops globally (Haverkort et al., 2009). Late blight is spread to newly emerged crops via air-borne spores from infected crops and volunteers. The infection causes necrosis of leaf tissues and rot development in the tubers, making them unmarketable (AHDB 2024). Historically, poor control of late blight has inflicted severe consequences, such as the Irish Potato Famine in the 1840s, which resulted in the death of one million people and widespread famine in Europe. The pressing issue of 70-80% total crop yield loss due to pathogens necessitates strategic interventions for sustainable potato production to address global food shortages (Yildiz and Ozgen, 2021). Typically, control has relied on multiple applications of fungicides, however changes in the pathogen population can result in resistance to fungicides, reducing fungicide efficacy. Equally there is increased pressure from governments, supermarkets and consumers to reduce pesticide inputs. To achieve control of this pathogen it is therefore vital that integrated pest management is employed, incorporating strategies such as control of primary inoculum sources, use of more resistant varieties and decision support systems (Cooke et al. 2011).

In response to these challenges, the development of disease-resistant potato varieties has become imperative to sustain potato production (Smith et al., 2019). Despite concerns about potential drawbacks, such as genetic uniformity and resistance breakdown (Fry et al., 2015), resistant varieties offer numerous benefits. These include a decreased dependency on chemical fungicides, leading to minimized environmental impacts and reduced financial burdens for farmers (Haverkort et al., 2009). Additionally, the use of resistant varieties contributes to enhanced crop resilience, ensuring stable and predictable yields by minimizing the impact of late blight outbreaks and fostering long-term food security (Saville et al., 2017). Several studies have underscored the effectiveness of resistant potato varieties in mitigating the impact of late blight. For instance, the work of Gebhardt et al. (2014) demonstrated the success of introgression of late blight resistance genes from wild potato species into cultivated varieties, offering durable and robust

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resistance. Additionally, studies by Vleeshouwers et al. (2011) and Jo et al. (2017) have clarified the genetic mechanisms underlying resistance, paving the way for targeted breeding programs. Reduced dependence on chemical inputs translates into cost savings for farmers, contributing to the overall sustainability of potato farming systems. This economic resilience is reinforced by the work in the Compendium of Potato Diseases (2017), which highlights the potential economic losses associated with late blight and the corresponding economic benefits of adopting resistant varieties.

In this comparison, nine distinct potato varieties were examined, each comprising a sample size of 10 plants, sampled at four locations within a 38-hectare field in Albersroda, Germany in 2023. The primary objective was to assess the comparative performance of a disease-resistant potato variety left untreated with fungicides, against standard varieties treated with two fungicide applications. Late blight disease pressure was high with most plants infected and severity ranging from 5 to 90% of the leaf area affected.

Results

The incidence and severity of late blight infection was assessed in all nine varieties on the 9th and 22nd August 2023. Incidence was high across all varieties with only one Connect plant on the 9th August and one Baltic Rose and Lilly plant recorded on the 22nd August as having no late blight symptoms. Clear differences in blight severity were observed across different potato varieties on both dates (Figure 3.1.5.1). Baltic Rose, Granada and Queen Anne had the highest disease severity, exceeding that of the most resistant variety left untreated with fungicide, Connect. Gaya consistently had the lowest disease severity.

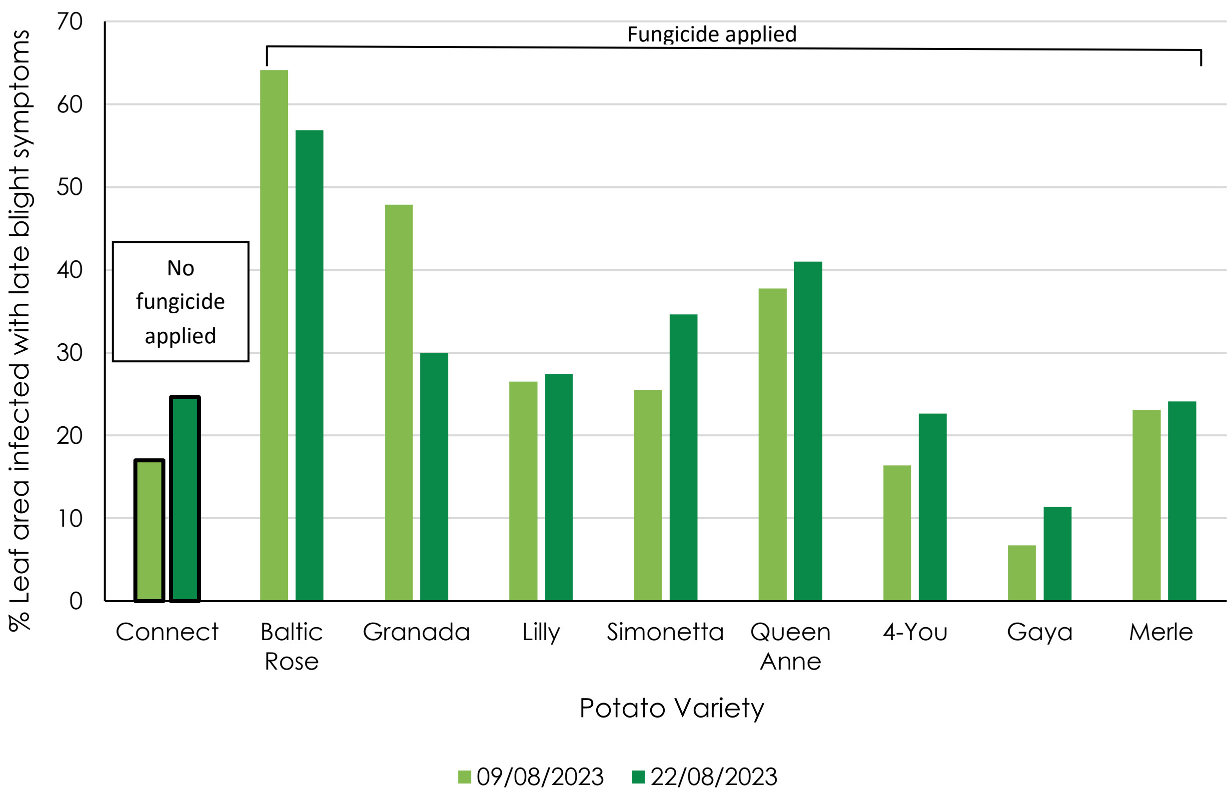

Figure 3.1.5.1: Percentage of leaf area infected with late blight symptoms in connect, untreated with fungicide compared to eight other varieties receiving fungicides, on the 9th and 22nd August 2023. Data for Queen Anne on the 22nd August is based on 10 plants whereas all other data is an average of 40.

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Connect left completely untreated with fungicides achieved the highest yield, closely followed by Gaya which had received fungicides. The lowest yield was recorded for Lilly (table 3.1.5.1). While sowing date and inherent yield potential of the variety will have also impacted yield, it is promising to see that the variety with high resistance to late blight and no fungicide inputs exceeded yield of all eight varieties supported with fungicides, clearly demonstrating the value of varietal resistance to disease. The high yield achieved by Gaya also shows the value of integrating disease resistance and effective use of fungicides in potato production.

Table 3.1.5.1: Sowing date and yield of each variety. Connect left completely untreated with fungicide and all other varieties receiving two fungicide applications.

Variety	Connect	Baltic Rose	Granada	Lilly	Simonetta	Queen Anne	4-You	Gaya	Merle
Sowing Date	6th April	28th April	5th May	3rd May	27th April	26th April	26th April	6th April	30th March
Yield dt/ha	480	360	320	120	380	320	340	420	340

Conclusions

This in field comparison has demonstrated the value of varietal resistance for control of late blight in potatoes. Connect, a highly resistant variety left untreated with fungicide reduced disease severity below that of several of the conventional varieties receiving two fungicide applications and achieved the highest yield. Of the conventional varieties using fungicides, Gaya achieved the lowest disease severity and highest yield, highlighting the value of incorporating disease resistance and effective use of fungicides in a disease control strategy. To maintain control of this challenging disease, it is vital that an integrated approach to disease management is utilised. Use of resistant varieties, where markets allow, can help to reduce disease pressure and therefore reduce reliance on fungicides. Where fungicides are used decision support systems should be employed to maximise efficacy.

Method

Design

Nine different potato varieties were cultivated in the same field. A late blight highly resistant variety, Connect was left completely untreated with fungicide, while all other eight conventional varieties received two standard fungicide applications, one on the 10th July 2023, and one on the 1st August 2023. The primary objective was to assess the comparative performance of a disease-resistant potato variety left untreated with fungicides against standard varieties receiving fungicides.

Data Collection

In four places per variety, the percentage of leaf area infected (severity) by late blight was assessed on 10 plants on the 9th and 22nd August 2023. From this an average incidence (percentage of plants infected) and severity score was calculated per variety. As there was no replication and multiple comparisons that could be made, statistical analysis has not been completed. Instead, the trends have been discussed.

Yield

The yield of each variety was measured as dt/ha.

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3.1.6. IPMWORKS: Using Decision Support Systems to improve canopy disease management in arable crops in Sweden

Authors: Andersson, B.[1] , Dearlove, E. [2], Francis, C. [2] and Ramsden M. [2]

1. SLU, Sweden
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Summary

Decision Support Systems (DSS) are essential tools to optimise fungicide applications for managing diseases. The use of a DSS allows farmers to make informed decisions, potentially reducing fungicide inputs without compromising disease management or yield. The use of a DSS was evaluated in seven fields in different regions of Sweden in 2023, using a DSS to guide fungicide application timings to manage septoria leaf blotch in winter wheat. Timing of fungicide applications were based on the Crop Protection Online CPO humidity model through the Swedish Board of Agriculture, which is also freely available across Europe on the IPM Decisions platform. The CPO septoria model estimates risk of septoria tritici infections in winter wheat. DSS-timed treatments effectively reduced disease severity and maintained yields, generally comparable to routine growth stage-based programmes and higher than untreated wheat. In four cases, the DSS determined low disease risk, so no fungicides were applied, no disease was observed and there was no recorded yield impact. Overall, the comparisons demonstrated the efficacy of DSSs in optimizing fungicide applications, allowing farmers to make informed decisions based on the risk of disease.

Introduction

In Sweden, and across Europe, severe infestations of leaf blotch diseases of wheat can be caused by septoria tritici blotch (*Zymoseptoria tritici*) and are driven by weather and host susceptibility (Jallie et al. 2020). This disease is often managed by routine growth stage-based spray programmes applied either as preventative measures at vulnerable growth stages or based on observations of early disease (Zadocks 1985). Early-stage disease severity assessments are thought to have little correlation with crop damage (Paveley et al. 1997; Jalli et al. 2020). Later disease assessments conducted during flowering are better correlated with yield losses but are too late to influence the timing of fungicide applications (Andersson et al. 2022). Using weather-based risk models to estimate future disease development at a time when fungicide applications are still possible show the greatest potential to optimize fungicide inputs (Jørgensen & Hagelskjær 2003; Burke & Dunne 2008; Jørgensen et al. 2020; Andersson et al. 2022).

In this comparison, a Decision Support System (DSS) from Crop Protection Online (CPO) and previously validated in Nordic and Baltic countries (Jørgensen et al., 2020), was used to guide the timing of applications of fungicides in seven fields within different regions of Sweden. The aim was to demonstrate the use of a DSS to time fungicide applications as part of integrated management of wheat diseases across seven farms. This DSS has also been integrated with the IPM Decisions Platform, making it accessible across Europe. The IPM DSS strategy was compared with several other growth stage-based treatment applications which the farmer would usually apply, and data was collected to determine the effectiveness of each approach in managing priority wheat diseases. This comparison was completed in collaboration with the Swedish University of Agricultural Sciences (SLU).

On each of the seven farms, two disease management approaches were implemented and compared with an untreated control. Approach 1: Under a 'farmer led' approach, an overall assessment of disease risk was made based on field condition, and where the farmer considered risk of septoria to be high, four alternative

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fungicide application programmes were implemented. Where the risk was considered low, no fungicides were applied. Approach 2: Under the 'DSS led' approach, fungicides were applied according to DSS output timings.

Results

In four of the seven fields, the farmer deemed the risk of disease to be low, and no fungicides were applied. In these same four fields, the DSS also determined no risk for septoria leaf blotch infection at any stage throughout the growing season, and so no fungicide applications were made. No disease was observed within these fields and therefore, there was no impact determined on yield.

In the three remaining fields, the DSS and/or farmer reported a high risk of septoria leaf blotch, and timing of fungicide applications was determined based on DSS outputs and compared to farmer-led approaches at key growth stages. Disease severity remained low across all fields in these comparisons, however, some differences in disease severity and yield of crop was observed between strategies. These are summarized according to field.

Field 1: Emtunga gård

In this field, as the farmer deemed the risk of disease to be high, four different fungicide strategies were applied with between 0 to 3 fungicide applications applied at key growth stages and compared to an untreated area and the DSS approach (table 3.1.6.1). There was no risk determined by the septoria DSS and therefore no application of fungicide in this strategy. Disease was significantly lower in areas of the field that received at least one fungicide application compared to the untreated and DSS strategy. However, there was no significant difference between treatments receiving 1, 2 or 3 fungicide applications in disease levels.

Differences in yield between treatments were small with yield ranging between 10.20 and 10.81 t/ha. The highest yield was achieved by the treatment receiving two fungicide applications, significantly higher than a growth stage 47 application of Ascra Xpro, the untreated and the DSS treatment.

Table 3.1.6.1: Timing, growth stage and product information for six different fungicide strategies of winter wheat in an 'in-field' comparison, field 1. *Decision Support System: Timing of fungicide application was determined based on high-risk outputs of the Crop Protection Online septoria humidity model.

Strategy	Fungicides applied	Crop growth Stage at application (Zadoks et al. 1974)	Date of fungicide application	Leaf 1 Septoria (%) 13th July 2023	TFI	Yield (t/ha)
1	Untreated	NA	-	18 a	0.0	10.43 bc
2	Ascra Xpro 0.75 l/ha	39	26th May	5 b	0.5	10.54 ab
3	Ascra Xpro 0.75 l/ha	47	3rd June	5 b	0.5	10.47 bc
4	Ascra Xpro 0.75 l/ha Balaya 0.5 l/ha	39 55	26th May 8th June	5 b	0.8	10.81 a
5	Folicur Xpert 0.33 l/ha Ascra Xpro 0.75 l/ha Balaya 0.5 l/ha	32 39 55	9th May 26th May 8th June	7 b	1.2	10.65 ab
6	DSS*	NA	-	12 a	0.0	10.20 c

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Field 2: Forsby

In this field, as the farmer deemed the risk of disease to be high, four different fungicide strategies were applied with between 0 to 3 fungicide applications applied at key growth stages and compared to an untreated area and the DSS approach (table 3.1.6.2). High risk was determined by the septoria DSS based on localised weather data and therefore one application of a fungicide was applied on the 19th June 2023. Disease severity was low across all treated sections of the field with between 0.5 and 0.7% infestation observed. In the untreated section, disease severity was still low at 4.4% but significantly higher than all other treated sections. Given the low disease pressure, yield did not differ significantly across any part of the field regardless of strategy, however all strategies receiving fungicides did yield slightly higher than the untreated.

Table 3.1.6.2: Timing, growth stage and product information for six different fungicide strategies of winter wheat in an 'in-field' comparison, field 2. *Decision Support System: Timing of fungicide application was determined based on high-risk outputs of the Crop Protection Online septoria humidity model.

Strategy	Fungicides applied	Crop growth Stage at application (Zadoks et al. 1974)	Date of fungicide application	Leaf 1 Septoria (%) 13th July 2023	TFI	Yield (t/ha)
1	Untreated	NA	-	4.4 a	0.0	11.16 a
2	Ascra Xpro 0.75 l/ha	39	31st May	0.7 b	0.5	11.25 a
3	Ascra Xpro 0.75 l/ha	47	8th June	0.5 c	0.5	11.36 a
4	Ascra Xpro 0.75 l/ha Balaya 0.5 l/ha	39 55	31st May 15th June	0.5 c	0.8	11.67 a
5	Folicur Xpert 0.33 l/ha Ascra Xpro 0.75 l/ha Balaya 0.5 l/ha	32 39 55	15th May 31st May 15th June	0.6 bc	1.2	11.49 a
6	Ascra Xpro 0.75 l/ha	DSS*	19th June	0.5 c	0.5	11.47 a

Field 3: Staby säteri

In this field, as the farmer deemed the risk of disease to be high, four different fungicide strategies were applied with between 0 to 3 fungicide applications applied at key growth stages and compared to an untreated area and the DSS approach (table 3.1.6.3). High risk was determined by the septoria DSS based on localised weather data and therefore one application of a fungicide was applied on the 21st June 2023. Disease severity was low across all treated sections of the field with no septoria symptoms observed, however tan spot was recorded. As with septoria, tan spot is favoured by long periods of dew or rain. Two applications of fungicide resulted in the lowest disease severity of tan spot which was significantly lower than the untreated section of the field. Differences in yield were small with 6.60t/ha achieved where no fungicide was applied, reaching 7.03t/ha where one fungicide application was applied at growth stage 47. The DSS strategy achieved a lower yield of 6.47t/ha, it's likely that the application based on septoria risk was a bit too late to control tan spot.

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*Table 3.1.6.3: Timing, growth stage and product information for six different fungicide strategies of winter wheat in an 'in-field' comparison, field 3. *Decision Support System: Timing of fungicide application was determined based on high-risk outputs of the Crop Protection Online septoria humidity model.*

Strategy	Fungicides applied	Crop growth Stage at application (Zadoks et al. 1974)	Date of fungicide application	Leaf 1 Tan Spot (%) 26th July	TFI	Yield (t/ha)
1	Untreated	NA	-	6.5 a	0.0	6.60 bc
2	Ascra Xpro 0.75 l/ha	39	24th May	2.0 ab	0.5	7.00 a
3	Ascra Xpro 0.75 l/ha	47	9th June	2.0 ab	0.5	7.03 a
4	Ascra Xpro 0.75 l/ha Balaya 0.5 l/ha	39 55	31st May 14th June	1.4 b	0.8	6.86 ab
5	Folicur Xpert 0.33 l/ha Ascra Xpro 0.75 l/ha Balaya 0.5 l/ha	32 39 55	24th May 31st May 14th June	2.0 ab	1.2	6.68 abc
6	Ascra Xpro 0.75 l/ha	DSS*	21st June	2.5 ab	0.5	6.47 c

Economic assessment

For each of the three fields in which fungicide applications were made, the Treatment Frequency Index (TFI, using equation 1) and partial cost-benefit analysis were calculated. In all cases, the TFI for DSS treatment was equal to, or below that of all other treatments, apart from the untreated crop.

Economic analysis calculated the total cost of all products, plus a standard application cost per treatment. Product costs and standard application costs were provided by the SLU. Cost of spray application is estimated as 17.61 EURO/application, and the value of wheat was estimated as 247.48 EURO/Tonne. Based on these figures, the economic profit/loss is estimated for each treatment relative to the untreated treatment on each of the three fields on which fungicides were applied.

Table 3.1.6.4: Cost assigned to each product applied

Product	Cost (EURO/litre)
Ascra Xpro	56.36
Balaya	59.16
Folicur Xpert	47.24

Table 3.1.6.5: Field 1: Emtunga gård partial economic analysis

Strategy	TFI	Yield (t/ha)	Yield value (EURO/ha)	Costs (EURO/ha)	Yield value – costs	Rank (highest to lowest)
1	0.0	10.43 bc	€ 2,572.04	€ 0.00	€ 2,572.04	1
2	0.5	10.54 ab	€ 2,599.16	€ 61.92	€ 2,537.24	3
3	0.5	10.47 bc	€ 2,581.90	€ 61.92	€ 2,519.98	4
4	0.8	10.81 a	€ 2,665.75	€ 111.20	€ 2,554.55	2
5	1.2	10.65 ab	€ 2,626.29	€ 146.53	€ 2,479.76	6
6	0.0	10.20 c	€ 2,515.32	€ 0.00	€ 2,515.32	5

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Table 3.1.6.6: Field 2: Forsby partial economic analysis

Strategy	TFI	Yield (t/ha)	Yield value (EURO/ha)	Costs (EURO/ha)	Yield value – costs	Rank (highest to lowest)
1	0.0	11.16 a	€ 2,752.06	€ 0.00	€ 2,752.06	3
2	0.5	11.25 a	€ 2,774.25	€ 61.92	€ 2,712.33	5
3	0.5	11.36 a	€ 2,801.38	€ 61.92	€ 2,739.46	4
4	0.8	11.67 a	€ 2,877.82	€ 111.20	€ 2,766.63	1
5	1.2	11.49 a	€ 2,833.43	€ 146.53	€ 2,686.91	6
6	0.5	11.47 a	€ 2,828.50	€ 61.92	€ 2,766.58	2

Table 3.1.6.7: Field 3: Staby säteri partial economic analysis

Strategy	TFI	Yield (t/ha)	Yield value (EURO/ha)	Costs (EURO/ha)	Yield value – costs	Rank (highest to lowest)
1	0.0	6.60 bc	€ 1,627.56	€ 0.00	€ 1,627.56	3
2	0.5	7.00 a	€ 1,726.20	€ 61.92	€ 1,664.28	2
3	0.5	7.03 a	€ 1,733.60	€ 61.92	€ 1,671.68	1
4	0.8	6.86 ab	€ 1,691.68	€ 111.20	€ 1,580.48	4
5	1.2	6.68 abc	€ 1,647.29	€ 146.53	€ 1,500.76	6
6	0.5	6.47 c	€ 1,595.50	€ 61.92	€ 1,533.58	5

In field 1, Emtunga gård, the total range in margin over fungicide costs (yield value – costs) was 92.28 EURO/ha. In field 2, Forsby, the total range in margin over fungicide costs was 79.72 EURO/ha, and in field 3, Staby säter, the range was slightly wider, 170.92 EURO/ha. At all three sites, treatment 5, which included three applications of fungicide had the lowest margin over fungicide cost. Treatment 3, guided by the DSS was ranked 5th at Emtunga gård however the top 5 programmes were all very close, with only 57 EURO/ha between 1st and 5th. At Forsby the DSS was ranked 2nd, by only 0.04 EURO/ha to treatment 4 which received two fungicide applications. At Staby säter due to a lower yield, the DSS was less successful being ranked 5th, 138 EURO/ha behind treatment 3 which also received a single fungicide application, but slightly earlier in the season. At this site, however tan spot was the dominant disease and the model is designed for septoria control.

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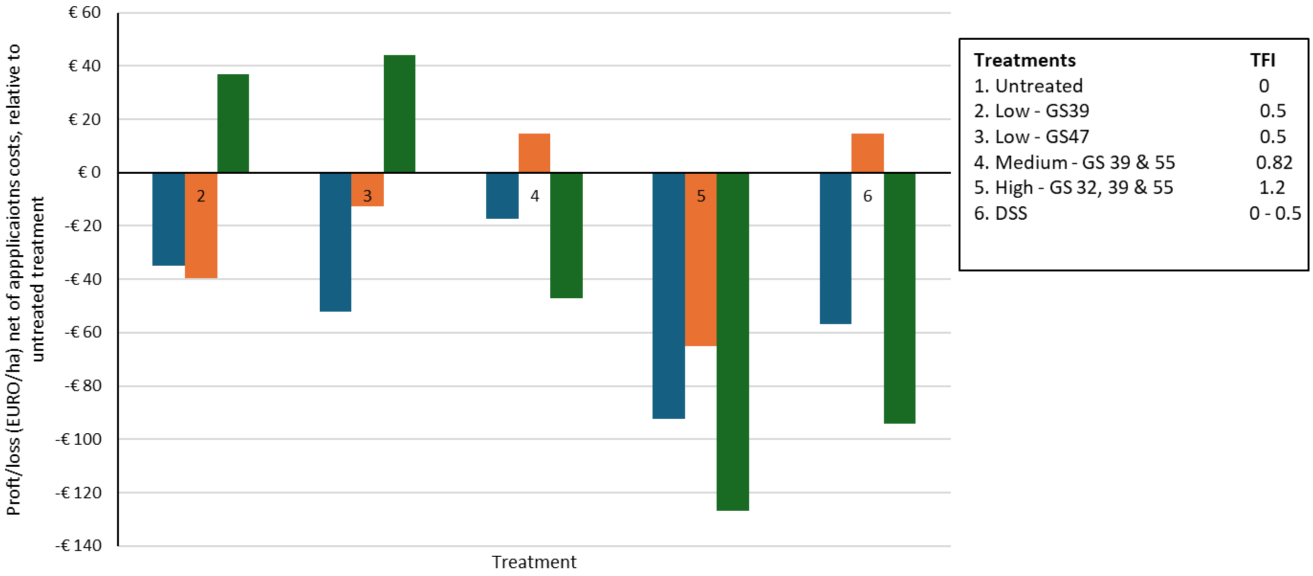

Table 3.1.6.1: Margin over fungicide costs relative to the performance of the untreated strategy. Blue shows data from field 1, orange field 2 and green field 3.

Conclusions

Of the seven fields investigated in this comparison, four were deemed at low risk of a damaging disease epidemic and as such no fungicides were applied by the host farmer or under the DSS strategy. In these cases, the DSS aligned the farmers own assessment that there was a low risk of septoria at their location, and subsequent field observations supported these decisions.

At two sites, Forsby and Staby säteri, one fungicide application was prescribed by the DSS. At Forsby, this resulted in an increase in yield compared to the untreated, and the second highest margin over fungicide cost. At Staby säteri, the dominant disease was tan spot and although the DSS recommended a fungicide application to control septoria, yield was statistically comparable to the untreated, suggesting that the model is less effective when tan spot is present. In field 3, Emtunga gård, in which the DSS did not prescribe an application, the DSS treatment achieved a lower yield than where fungicides were applied, however differences in yield and margin over fungicide cost were small.

In all cases, the DSS treatment fungicide Treatment Frequency Index (TFI) was either zero or 0.5, equivalent to the untreated/lowest farmer-led approaches. Partial economic analysis revealed that the most intensive treatment (treatment 5, TFI 1.2) was consistently the least profitable treatment. Consultation of the DSS provided reliable guidance on disease management, supporting effective treatment while minimising fungicide applications where septoria was the key concern.

Combining the consultation of a decision support system with a farmer or advisors knowledge of disease epidemics shows great potential in optimising fungicide programmes. Not applying fungicides in a very low disease pressure season is a difficult decision to make. A low risk rating from a DSS can give growers the confidence not to apply fungicides in these scenarios. In slightly higher disease risk scenarios where the value of a fungicide is debated, again a DSS can support a single application of fungicide to optimise yield. The examples demonstrated here highlight scenarios where a DSS can add most value, in supporting the reduction of fungicide usage where not deemed necessary, saving the grower money and reducing the impact of pesticides on the environment.

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Methods

Field locations

Three locations across Sweden were used in this comparison, in Staby säteri, Forsby and Emtunga gård.

Strategies

In small plot ($50m^2$) field trials with four replicates of each strategy, applications of fungicides were timed based on DSS risk outputs or a routine growth stage spray programme. Fungicide products and application rates applied were outlined by the farmers, as part of their usual spray programme based on crop development stage (see table 3.1.6.4.) and did not differ between farms.

Table 3.1.6.4: Key growth stages used to determine the application timing of fungicide treatments in Sweden.

Growth Stage (Zadocks et al. 1974)	Description
GS31–33	fully emerged leaf 3
GS39	flag leaf fully emerged
GS47	between flag leaf and ear emergence
GS55	spray to top up foliar disease control

Strategies had either one, two or three fungicide applications. For the DSS strategy, fungicide applications were guided according to outputs of the CPO humidity model DSS.

The DSS

In the DSS strategy, timings of fungicide applications were based on CPO humidity model through the Swedish Board of Agriculture. The CPO Septoria model estimates risk of septoria tritici blotch infections in winter wheat. Weather data from GS 32 to GS 69 are used. Fungicides are recommended after a minimum of 4 days with > 1mm rain in susceptible cultivars between GS 32 and GS 69. In resistant cultivars risk of attack is assumed after 5 days with rain (>1mm) between GS 37 and GS 69. This DSS was created by Aarhus University and SEGES and released in Denmark in 2000.

Assessments

Severity of disease symptoms was assessed in each field location (table 3.1.6.5.). During each assessment, percentage leaf area with symptoms of disease was reported for eventual leaves 1, 2 and 3. In each field location, 25 randomly sampled plants were taken from a random distribution within each strategy. Average percentage cover of leaves with symptoms of disease were calculated and reported.

Table 3.1.6.5: Date and growth stage of disease assessments in each field

Location	Date	Growth Stage
Emtunga gård	27/06/2023 13/07/2023	GS70 GS81
Forsby	30/06/2023 13/07/2023	GS70 GS81
Staby säteri	26/07/2023	GS87

Yield

Yield differences between treatments were quantified by the field trial harvester. Values were adjusted to 15% moisture content.

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Treatment Frequency Index (TFI)

Treatment frequency index (TFI) was also determined by calculating the proportion of the full label rate that each pesticide product was used at and summing the result for each product within each strategy, as shown in Equation 1.

$$TFI = \sum \frac{Application\ Rate\ (^{L}/_{ha})}{Registered\ Dose\ (^{L}/_{ha})}$$ **Equation 1**

Data Analysis

Data analysis was conducted by the Swedish University of Agricultural Sciences (SLU). Significant differences in disease and yield between treatments were determined by Analysis of Variance (ANOVA) and Tukey's multiple comparisons.

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3.1.7. IPMWORKS: Using Decision Support Systems to improve Barley Yellow Dwarf Virus (BYDV) management in England (Part 1)

Authors: Telling, S.[1] Dearlove, E.[1] and Francis, C.[1]

1. ADAS, England

Summary

Barley yellow dwarf virus (BYDV) significantly impacts UK cereals, and severe infestations can cause up to 84% yield loss in winter wheat. Transmitted mainly by bird cherry-oat aphids (*Rhopalosiphum padi*), and grain aphids (*Sitobion avenae*), control has shifted from a dependence on neonicotinoid seed treatments and application of pyrethroid insecticides towards integrated pest management (IPM) approaches. The UK T-sum decision support system (DSS) aids in managing BYDV by predicting aphid generations for targeted insecticide application. As this model does not include observation data it can overestimate infection risk, however when consulted alongside field observations it is a useful tool for targeting interventions and avoiding unnecessary applications. This 'in-field' comparison carried out in the east of England in autumn 2022 follows three strategies for reducing BYDV in UK winter cereals: 1) a risk-averse approach with maximum insecticide use at fixed intervals; 2) a current IPM standard using the T-sum DSS for risk-based insecticide application, and 3) a holistic approach combining the DSS tool and farm scale monitoring to determine the need for and timing of insecticides. Few aphids were found during assessments in the autumn. This pointed to relatively low risk of BYDV infection, confirmed by low levels of BYDV symptoms observed in the following spring. Yield analysis found there to be small but significant differences between treatments, and economic analysis showed small differences in the profit margin after accounting for number of sprays between the standard IPM and holistic approaches, but a large negative margin between these and the risk averse approach. This comparison found the risk-adverse approach did not significantly reduce BYDV vectors or infection and had lower profit margins. The standard IPM or a holistic approach were effective in managing the risk of BYDV to the crop in this comparison. The use of DSS and field monitoring allows for better risk assessment and a reduction in insecticide use in low pressure years.

Introduction

Barley yellow dwarf virus (BYDV) is the main virus disease of cereals in the UK, capable of causing yield losses of up to 80% in winter barley and 84% in winter wheat (Dendryver et al., 2010; Nancarrow et al., 2021). In the UK BYDV is transmitted primarily by bird cherry-oat aphid (*Rhopalosiphum padi*) and grain aphid (*Sitobion avenae*). Control of these aphids has changed dramatically in recent years, with the loss of neonicotinoid seed treatments in 2019 and the appearance of moderate levels of pyrethroid resistance in *S. avenae* (Foster et al., 2014; Holland et al., 2019). Control now largely relies on foliar applications of insecticides most of which fall within the pyrethroid class of active ingredients. Sustained or increased use of pyrethroids risks stronger or new forms of resistance appearing in BYDV vectors. Concerns over the optimal timing of foliar insecticides, overuse of insecticides and insecticide resistance mean that the development of integrated pest management (IPM) for BYDV is critically important. Resistance to pyrethroids has been recorded in the grain aphid in the UK (Foster et al., 2014), with the proportion of the population exhibiting the resistance trait differing between regions and over time (IRAG, 2021). In the bird cherry-oat aphid, there has been no record of reduced sensitivity to pyrethroids in the UK. Lower sensitivity possibly conferring resistance was reported in the Republic of Ireland (Walsh et al., 2020), however recent tests on the same and more aphid populations have found there to be no evidence of reduction in susceptibility to pyrethroids (George et al., 2022). Beyond Europe, populations of bird cherry-oat aphid do have traits that confer complete resistance to pyrethroids which highlights a possible risk of resistance development occurring (Wang et al., 2020; Gong et al., 2021;

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Wang et al., 2021). The current management guidance is that a foliar insecticide should only be considered if aphids are seen within the crop (Ramsden et al., 2017). Due to the difficulty in monitoring aphids, it is often risk averse to apply an insecticide if the risk in the region is deemed to be high, whereas the local risk may be low (White et al., 2023).

Knowing if and when to apply foliar insecticides to control BYDV is not straightforward. During the autumn, migrating aphids flying into cereals are responsible for initial BYDV infections. These aphids settle on and infect a relatively small number of plants in a crop with BYDV, referred to as primary infection. As the aphids reproduce, they begin to move away from the initially colonised plants to neighbouring plants and cause secondary spread of the virus. Primary infection is thought to be the main cause of infections in cold winters, while secondary spread is associated with the greatest yield impacts in mild winters (Halbert & Pike, 1985; Teulon et al., 1999). As it is very difficult to prevent primary infection, targeting aphids to prevent or slow secondary spread is thought to be the most effective way to minimise losses to BYDV with foliar insecticides (HGCA, 2003). In an effort to help growers with timing of sprays, a T-sum decision support system (DSS) is available online (AHDB, 2024). This model predicts the appearance of the second winged generation of aphids in the crop, which are the aphids associated with the start of secondary spread (HGCA, 2003). This generation begins to appear after 170 ‘degree days’ (DD) have accumulated, above a baseline temperature of 3°C. Using weather forecasts, the DSS carries out the calculation for the user and indicates when the second winged generation of aphids are likely to appear, recommending a crop inspection and for an insecticide to be considered if aphids are present. Although this DSS is the only tool available for BYDV management assistance, it is still viewed as rudimentary and likely to overestimate the risk from infection as it does not include parameters on aphid numbers or BYDV prevalence within the aphid population (White et al., 2023). Nonetheless, it is a progressive step towards better informed BYDV management.

This comparison carried out in the east of England in autumn 2022, demonstrated three different strategies for the reduction of BYDV in winter cereals that represents alternative approaches that could be implemented by cereal growers. A risk averse approach, where the maximum amount of insecticide permitted to be applied is used reflects an extreme pre-IPM, risk averse approach. Insecticides were applied at first spray window after 100% crop establishment. Subsequent sprays were applied at the next available spray opportunity, three weeks after the preceding spray. This continues until the maximum field rate for one season of insecticide is achieved. This is compared with an IPM approach, consulting the T-sum tool to aid with risk decision and spray timing. Application timings are as predicted by the T-sum DSS in the IPM Decisions platform. The tool is started on the first day of crop emergence. When the risk is ‘high’ (T-sum 170) this triggers guidance to check the crop for aphids. If aphids are present a spray should be applied at the next available opportunity. If aphids are not present immediately after T-sum 170, the tool is restarted, and T-sum returns to 0. Consultation of the DSS was stopped when the crop reaches growth stage 31 or on March 1st, whichever comes first. The final strategy is a holistic or forward-thinking approach which combines the use of a DSS with farm-wide monitoring of aphid vectors to assess the overall level of infestation and therefore risk. Insecticide application was applied when the second generation of cereal aphids appears in significant numbers in clusters observed across the farm. All insecticide applications were applied based on the host farmers determination of risk by way of aphid numbers within the crop. This comparison was carried out in collaboration with AHDB on Strategic Farm East.

Results

The field was drilled with winter wheat on the 10th October 2022, with emergence on the 24th October. The first risk averse spray was applied on the 29th October with consecutive sprays on 23rd November, 18th December and 14th January. The T-sum DSS reached T-sum 170 twice between emergence and growth stage 31, first on the 16th November, sprayed on the 23rd November, and the second on the 29th January (sprayed on 11th February). There were no insecticides applied with the holistic approach.

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A total of 36 aphids were observed at the first assessment on the 3rd November, all of which were *R. padi*. Four aphids were counted in the holistic approach tramlines, eight aphids in the risk averse tramlines and 24 in the standard IPM tramlines. There was a significant difference between the number of aphids in the standard IPM approach and the other strategies (df = 2, F = 3.92, P = 0.023) (figure 3.1.7.1). When this assessment was completed, only the risk adverse strategy had received an insecticide application. This therefore suggests that there was a natural variation in the spread of aphids across the field. At the second assessment on the 23rd November, no aphids were recorded.

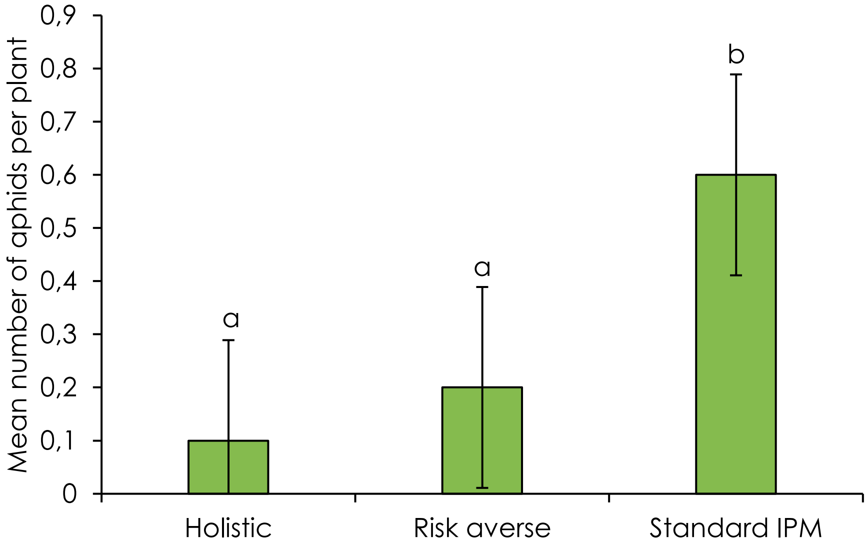

Figure 3.1.7.1: The mean number of BYDV vectors per plant recorded in the difference tramlines on the 3rd November. Bars represent the standard error of the mean. Bars followed by different letters are significantly different (P <0.05).

There was no significant difference between the percentage of BYDV symptoms (P = >0.05) on the 8th June, with the highest observed in the standard IPM (3.5%) followed by the holistic (1.3%) and the risk averse (1%) treatments (figure 3.1.7.2).

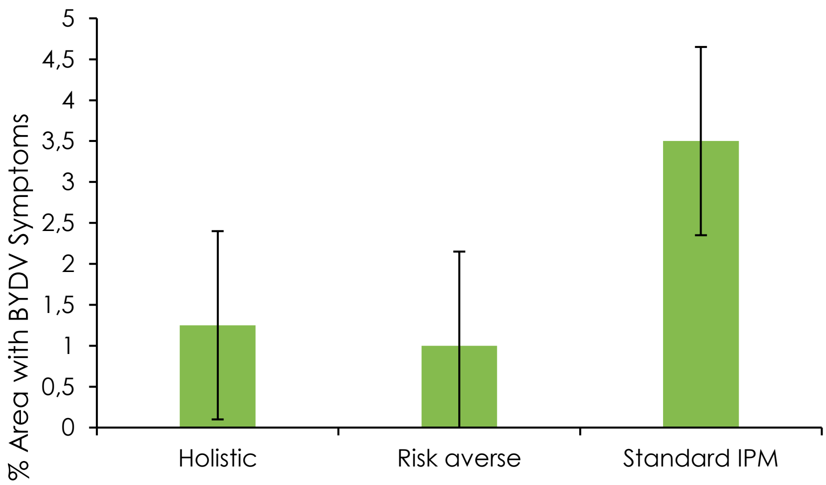

Figure 3.1.7.2: The mean area of tramline that had observed BYDV symptoms between different management approaches. Error bars represent the standard error of the mean.

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Yield was significantly lower in the holistic approach (8.1 t/ha), behind the risk averse approach (8.2 t/ha) and then the standard IPM approach (8.4 t/ha) (df = 2, F = 57.89, P = <0.001) (figure 3.1.7.3). However, given the low BYDV severity observed in the field, these differences are very small and not thought to be directly influenced by the BYDV strategies.

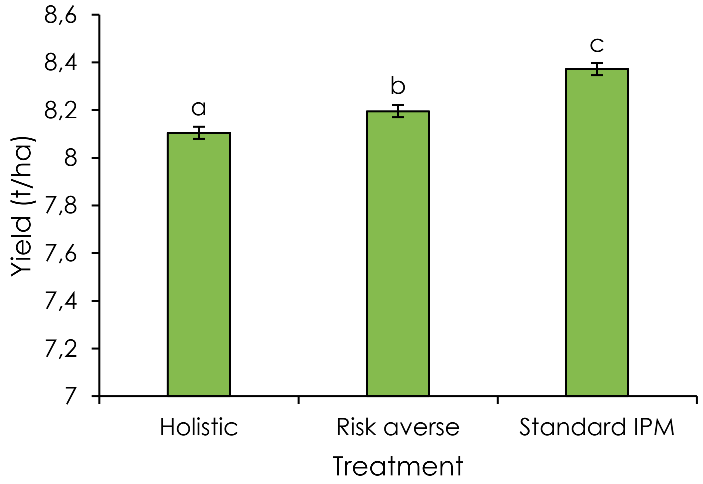

Figure 3.1.7.3: The mean harvested yield between different management approaches. Bars represent the standard error of the mean. Bars followed by different letters are significantly different (P <0.05).

Determining the efficacy of each strategy can also be done by assessing a relative approximation of the cost effectiveness of each approach, taking into account the grain price, cost of the insecticides and approximate cost of applying the insecticides. This uses the standard IPM approach as the baseline and the risk averse and holistic approach as the comparators. Based on a grain price of £200/t, the standard IPM approach, with two sprays and yielding 8.4t/ha produces an approximate return of £1,643/ha. The holistic approach, with no insecticides, returned approximately £22/ha less than the standard IPM approach despite yielding slightly lower. The risk averse approach, where four sprays were applied and yielding lower than the IPM approach, returned a reduction of £67/ha when compared to the baseline (table 3.1.7.1).

Table 3.1.7.1. The approximate cost effectiveness of each strategy taking into account yield, insecticide and labour costs.

	Yield (t/ha)	Output (£/ha)	Number of sprays	Cost of insecticide applications (£/ha)	Margin over insecticide cost (£/ha)	Difference to standard IPM strategy per ha
Standard IPM	8.371	1674.2	2	31.62	1642.58	n/a
Holistic	8.105	1621	0	0	1621.00	-£21.58
Risk averse	8.195	1639	4	63.24	1575.76	-£66.82

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Conclusion

Current BYDV management relies on insecticides to control cereal aphids in the autumn. Cultural control approaches, such as adjusting drill date can reduce risk, and commercial varieties exhibiting tolerance and/or resistance to BYDV are becoming more widespread and able to positively respond to fungal disease infection in addition. These are steps that represent a move away from control of the vectors but the use of insecticides to control aphids still remains the primary form of management (White et al., 2023). The performance of three strategies for BYDV management that represent different stages in sustainable pest management were compared in this comparison. Overall, the risk pressure from BYDV infection was low throughout the season.

A risk averse approach is a prophylactic strategy, which prioritises minimising vector abundance rather than treating according to risk. In reality, this is not an approach that is widely implemented, most farmers adopt more targeted applications, mainly to reduce the abundance of aphids in early crop establishment and reduce secondary populations if necessary. As the understanding of virus transmission and management, and the implications of insecticide use become better understood, more detailed approaches using DSS, varieties, and adjusted drilling dates are being integrated. In this comparison, the risk averse strategy did not produce significantly less vectors or infection than the other treatments and whilst the yield was not the lowest, the cost of applying four sprays reduced the margin over insecticide cost. The standard IPM approach, reflecting most common practice in the UK, is the current recommended strategy, where DSS consultation informs growers when the second generation of aphids was likely to occur and spread the virus between plants. Despite reporting the highest number of aphids and the highest percentage area with symptoms, this treatment recorded the highest yield, and greatest return on investment. Finally, the holistic method is a modification to the standard IPM approach, whereby the grower makes an informed decision on whether to apply a spray based upon the number of aphids seen in the crop. Here, this was defined as being multiple clusters of aphids within the test field. As these were not observed, an insecticide was not applied. There was a significant difference in yield between this strategy and the standard IPM approach, but the economic margin between the strategies is small. This holistic approach is more forward thinking, and defaults to no applications being made unless unavoidable.

Overall, there is a benefit of an informed approach to BYDV management. The implications for the overuse of insecticides have been well reported, with wide environmental, economic and social impacts (White et al., 2023). In cereals, pyrethroids are currently the only insecticides available and these have the potential to kill a range of beneficial insects, including natural enemies of virus vectors (Jansen et al., 2011). Furthermore, the risk of further resistance to pyrethroids in aphid populations has the capacity to severely compromise future BYDV management using insecticides. The current recommended guidance, using the T-sum model, is rudimentary and likely to be too conservative. For much of England, in a crop emerging in late September the T-sum model could support up to four applications even if the actual risk of BYDV is low. It is therefore important that crops are monitored, and an insecticide is only applied if aphids are found. Nonetheless, it has been an important addition to the BYDV management toolbox, where guidance for when to target monitoring is important for saving time and allowing for better timing of insecticide use.

The holistic approach is the next step in this strategy where an informed grower, knowledgeable of risk, makes decisions based on the understanding of likely BYDV incidence on farm and the expected outcomes in terms of yield loss. This requires higher levels of taxonomic knowledge and pest phenology to accurately determine risk from BYDV. The importance of this is that insecticide use could be better linked with actual risk. The T-sum model makes assumptions that each season, aphids arrive on the day of crop emergence and that all aphids carry BYDV, but that it is known now that size of the aphid migration and proportion of the aphid population with BYDV differs interannually (White et al., 2023). Therefore, the model is conservative in its estimations of risk. Applying on-farm monitoring and a DSS to assist in informing growers of risk is the best way to manage BYDV infection. Advances in new DSS and monitoring tools means that 'in-field'

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monitoring and assistance in decision making is ever more practical. Image analysis of aphids in water traps (Gao, 2023) and on plants (Li et al., 2023) have the capacity to reduce the need for specialist taxonomic knowledge when assessing aphids in fields, and recent development of DSS with inputs for aphids, virus, agronomic and economic parameters can better predict when periods of high risk are likely to be (White et al., 2023). This is especially important when regional and local variations in aphid and virus pressure can lead to high-risk areas that may be underestimated by alternative strategies.

Methods

Field site

The field site chosen was a winter wheat field (var. Skyscraper) encompassing 27ha. Skyscraper is a variety that does not possess tolerance or resistance to BYDV infection. Topography and soil attributes were assessed using NVDI to ensure uniformity across the tramlines and ensure there were no features that would confound treatment effects. In this comparison, each strategy was replicated twice in tramlines that were approximately 200m long. Assessed tramlines ran between the headland tramlines to mitigate edge effects (figure 3.1.7.4).

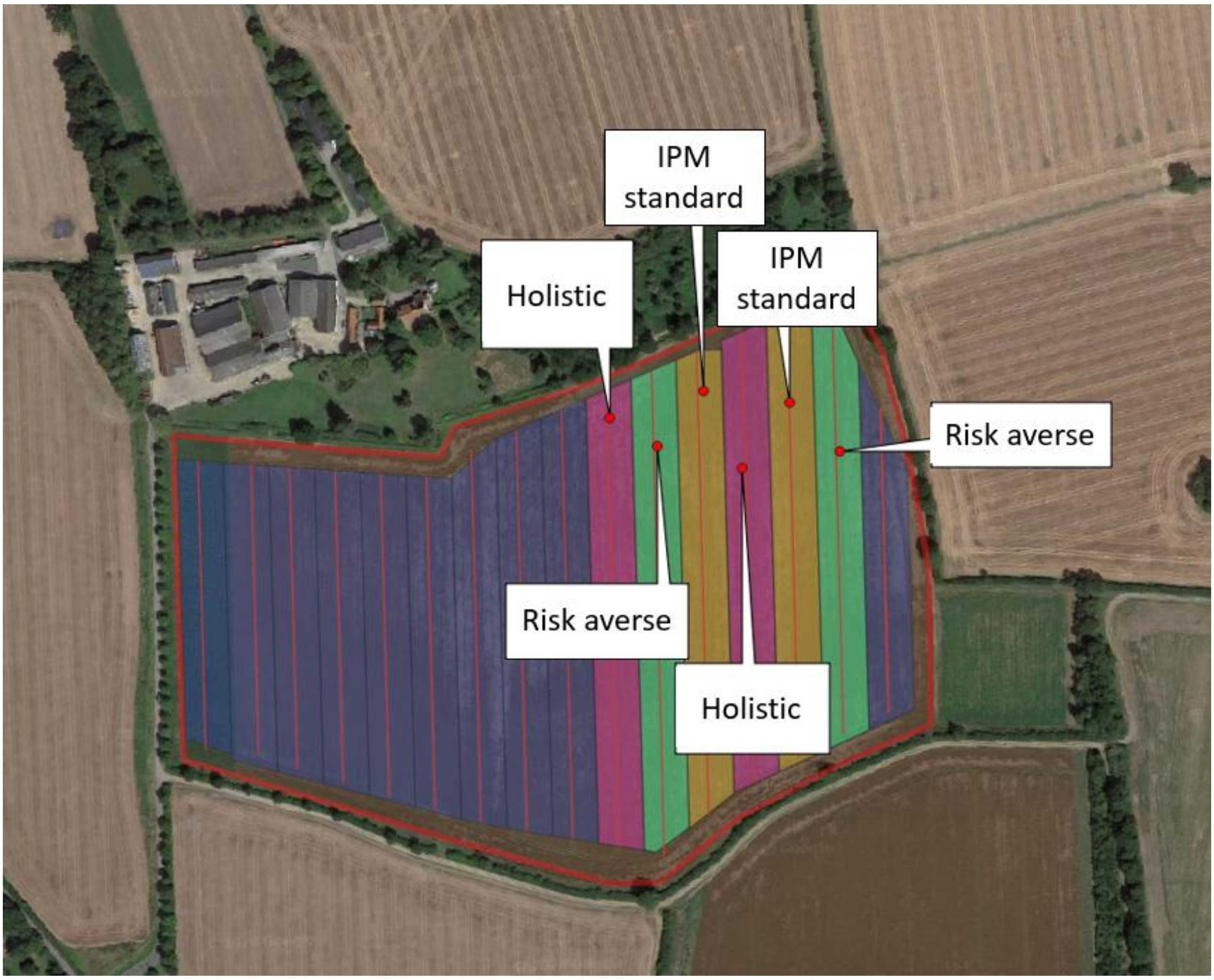

Figure 3.1.7.4: Layout of the tramlines and corresponding treatments.

Treatments

The risk averse treatment schedule began on the first suitable spray date after 50% emergence, followed by subsequent applications approximately every three weeks. The standard IPM strategy involved running the

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T-sum model each week between crop emergence and GS31. The threshold of T-sum 170 is the point at which risked is deemed to be high if aphids are present within the crop, therefore the host was informed close to T-sum 170 that monitoring of crops was necessary and an application required if aphids present. The holistic approach combined the use of the T-sum model with regular monitoring (biweekly) of aphids within the crop. If multiple clusters of aphids were observed, then the crop would be sprayed.

Applications

All treatments were sprayed with Hallmark Zeon (lambda-cyhalothrin) at a maximum rate of 50 ml/ha using a 24 m tractor mounted sprayer boom. The maximum field rate for a single season in winter wheat is 200 ml/ha, limiting the number of applications to four. Sprays were applied as near to recommended timings as was possible, with the host's discretion on whether a spray could be applied due to weather or ground conditions.

Assessments

Assessments on aphid population, BYDV symptoms and yield were performed within the growing season. Two aphid infestation assessments took place in the first and last weeks of November. This involved the counting of aphids on ten plants at ten points equidistantly located along each tramline. Numbers of grain aphids and bird cherry-oat aphids were assessed separately. The assessment of BYDV symptoms consisted of estimating the percentage area with symptoms (yellowing leaves and stunting) on a 2m wide section of the tramline. This was repeated at 10 intervals along each tramline. The best time to assess symptoms is between GS39 and GS59, as before this symptoms are not fully expressed and after this leaf senescence can hide visible symptoms. Yield was taken from a combine harvester with yield mapping capabilities.

Data analysis

Data from aphid infestation and BYDV symptoms were analysed through ANOVA. Significant results were followed by a post-hoc Duncan's Multiple Range test to identify significant differences between treatments. Combine harvester yield mapping data was extracted and mapped to link with tramlines for respective treatments. Mean yields for each tramline was calculated and the treatment differences were analysed with ANOVA, with a Duncan's Multiple Range test used to identify the significance of the interactions of the treatments.

Economic analysis

A rudimentary economic analysis was performed to identify the possible financial implications of each treatment. Figures for grain price are the five-year average of £200/ha (AHDB, 2023). Treatment costs are approximations for how much a farmer is likely to pay to apply an insecticide on a single occasion, figures are taken from the John Nix Pocketbook (Redman, 2023). Within treatment costs are: the cost of the insecticide product, lambda-cyhalothrin, at £4.88/ha; machinery costs for spraying (based on 200L/ha and 24 m boom) at £8.26/ha; the assumed labour cost based on the minimum wage, at £8.91/hr; and the time to apply a spray in cereals at 0.3 hours/ha. In total, treatment costs per spray applied was £15.81.

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3.1.8. IPMWORKS: Using Decision Support Systems and variety to improve Barley Yellow Dwarf Virus (BYDV) management in England (Part 2)

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2. ADAS, England

Summary

Barley yellow dwarf virus (BYDV) significantly impacts UK cereals, causing up to 84% yield loss in winter wheat. Transmitted mainly by bird cherry-oat and grain aphids, control has shifted from neonicotinoid seed treatments to pyrethroid insecticides. Integrated pest management (IPM) is crucial due to resistance and timing challenges. The AHDB's T-sum decision support system aids in managing BYDV by predicting aphid generations for targeted insecticide application, though it may overestimate infection risk. This 'in-field' comparison compares the use of decisions support systems (DSS) in two winter wheat fields in the east of England in autumn 2023, one containing a variety susceptible to BYDV, the other containing a variety marketed as "resistant" to BYDV. Two DSS were consulted, first the T-sum DSS, and a more advanced DSS, ACroBAT, to assess the risk of spread of BYDV in each field, and support decisions on whether or not insecticide treatment applications were required. During a very wet autumn, few aphids were found during assessments in either field. Consultation of both DSS guided towards a low risk of BYDV in either variety, and no applications were made. Symptoms of BYDV were assessed in both varieties, and found to be very low. The use of DSS and field monitoring allows for better risk assessment and a reduction in insecticide use in low pressure years.

Introduction

Barley yellow dwarf virus (BYDV) is the main virus disease of cereals in the UK, capable of causing yield losses of up to 80% in winter barley and 84% in winter wheat (Dendryver et al., 2010; Nancarrow et al., 2021). It is transmitted primarily by bird cherry-oat aphid (*Rhopalosiphum padi*) and grain aphid (*Sitobion avenae*). Control of these aphids has changed dramatically in recent years, with the loss of neonicotinoid seed treatments in 2019 and the appearance of moderate levels of pyrethroid resistance in *S. avenae* (Foster et al., 2014; Holland et al., 2019). Control now relies on foliar applications of insecticides most of which fall within the pyrethroid class of active ingredients, meaning management has progressed little in forty years. Increased use of pyrethroids risks stronger or new forms of resistance appearing in BYDV vectors. Concerns over the optimal timing of foliar insecticides, overuse of insecticides and insecticide resistance mean that the development of integrated pest management (IPM) for BYDV is critically important. Resistance to pyrethroids has been recorded in the grain aphid in the UK (Foster et al., 2014), with the proportion of the population exhibiting the resistance trait differing between regions (IRAG, 2021). In the bird cherry-oat aphid, there has been no record of reduced sensitivity to pyrethroids in the UK. Lower sensitivity possibly conferring resistance was reported in the Republic of Ireland (Walsh et al., 2020), however recent tests on the same and more aphid populations have found there to be no evidence of reduction in susceptibility to pyrethroids (George et al., 2022). Beyond Europe, populations of bird cherry-oat aphid do have traits that confer complete resistance to pyrethroids which highlights a possible risk of resistance development occurring (Wang et al., 2020; Gong et al., 2021; Wang et al., 2021). The current management guidance is that a foliar insecticide should only be considered if aphids are seen within the crop (Ramsden et al., 2017). Due to the difficulty in monitoring aphids, it is often risk averse to apply an insecticide if the risk in the region is deemed to be high, whereas the local risk may be low (White et al., 2023).

Knowing if and when to apply foliar insecticides to control BYDV is not straightforward. During the autumn, migrating aphids flying into cereals are responsible for most BYDV infections. These aphids settle on and

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infect a relatively small number of plants in a crop with BYDV, referred to as primary infection. As the aphids reproduce, they begin to move away from the initially colonised plants to neighbouring plants and cause secondary spread of the virus. Primary infection is thought to be the main cause of infections in cold winters, while secondary spread is associated with the greatest yield impacts in mild winters (Halbert & Pike, 1985; Teulon et al., 1999). As it is very difficult to prevent primary infection, targeting aphids to prevent or slow secondary spread is thought to be the most effective way to minimise losses to BYDV with foliar insecticides (HGCA, 2003). In an effort to help growers with timing of sprays, AHDB made a T-sum decision support system (DSS) available online (AHDB, 2024). This model predicts the appearance of the second wingless (apterous) generation of aphids in the crop, which are the aphids associated with the start of secondary spread (HGCA, 2003). This generation begins to appear after 170 'degree days' (DD) have accumulated, above a baseline temperature of 3°C. For locations across the country and using weather forecasts, the DSS carries out the calculation for the user and indicates when the second wingless generation of aphids are likely to appear, recommending a crop inspection and for an insecticide to be considered if aphids are present. Consultation of the T-Sum model helps provide a measure of the risk of BYDV transmission, and targets in field monitoring, however the model assumes all aphids are carrying BYDV, and that aphid populations are unaffected by rainfall, abundance of natural enemies, and other factors known to influence the risk of BYDV. A new DSS under development by ADAS and AHDB known as ADAS-Crop BYDV Assessment Tool (ACroBAT) incorporates detail on the agronomy of the farm/ field (seed rate, drilling data, treatment costs, predicted yield and grain price), aphid numbers and proportion of aphids carrying BYDV. All aphid data is collated from the Rothamsted Insect Survey. With the proportion of aphids carrying BYDV from additional work carried out by Dr Martin Williamson (Rothamsted Research). The proportion of aphids carrying the virus is then taken from further information provided by Dr Williamson from the Brome's Barn suction trap. The fields in the 2023/2024 season were drilled on the 27th and 28th of October and used data on virus infection from Brooms Barn suction trap aphids caught during the 23rd to the 29th of October 2023 (Aphid bulletin No. 30). A total of 16 aphids were tested out of which 3 were positive for BYDV and 0 positive for CYDV (no other viruses were screened for). This produced a starting percentage infection of 19% of aphids carrying BYDV. ACroBAT provides more informed guidance to assessment based on the risk of BYDV infection, and initial assessments have shown this to support effective management (White et al. 2023). ACroBAT is operational but still under development and as such has no external user interface.

This comparison carried out in the east of England in autumn 2023 demonstrated the consultation of both the T-sum and ACroBAT DSS applied in one variety susceptible to BYDV, and another variety marketed in the UK as resistant to BYDV. Both the DSS were used in combination with field observations and insecticides only applied where observations indicate increasing aphid activity. A third strategy was included as a commitment to no insecticides, in which no applications would be made irrespective of DSS guidance or field observations. This comparison was completed on an AHDB Strategic East Farm in collaboration with AHDB and NIAB (National Institute of Agricultural Botany).

Results

2023/2024 autumn overview

Two fields were located in Norfolk, UK, following winter oats and were drilled in the last week of October 2023 and emerged on the 17th of November. Rainfall throughout October and shortly after crop emergence led to high soil moisture levels in both fields, limiting field access with machinery (figure 3.1.8.1). The risk of spread of BYDV was monitored using the T-Sum and ACroBAT DSS and field observations of aphid and natural enemy abundance. Local aphid populations were assessed via the Rothamsted Insect Survey suction trap network (https://insectsurvey.com/suction-trap) from the Brooms barn trap which is the nearest trap to the field, approximately 55km. Insecticide application decisions were agreed with the host farmer based on variety, DSS outputs, field and regional observations, as well as consideration of the soil conditions. The number of aphids observed regionally were relatively low compared with previous yearly averages during

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the early stages of crop development (figure 3.1.8.2). Aphid counts in the fields at points of high risk of winged aphids reported by the T-Sum model were low (table 3.1.8.1 and table 3.1.8.2), and the ACroBAT model forecasts a low risk throughout the period from crop emergence until late November. As both models reported low risk of BYDV, and travel on the wet soil risked damage to the crop, no insecticides were applied to any of the strategies in either field.

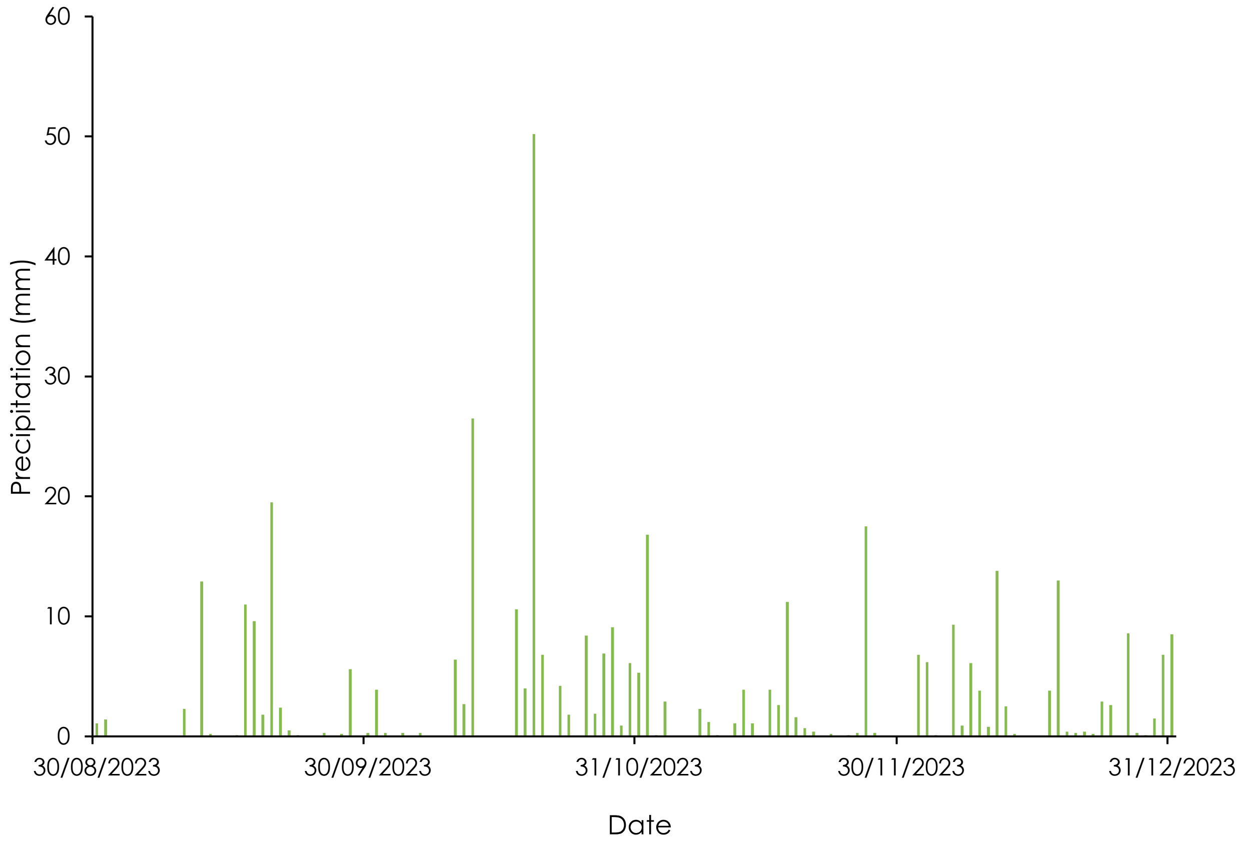

Figure 3.1.8.1: Rainfall at the farm from the 30th August until the 31st December 2023. Extracted from Open Meteo on the IPM Decisions Weather Service.

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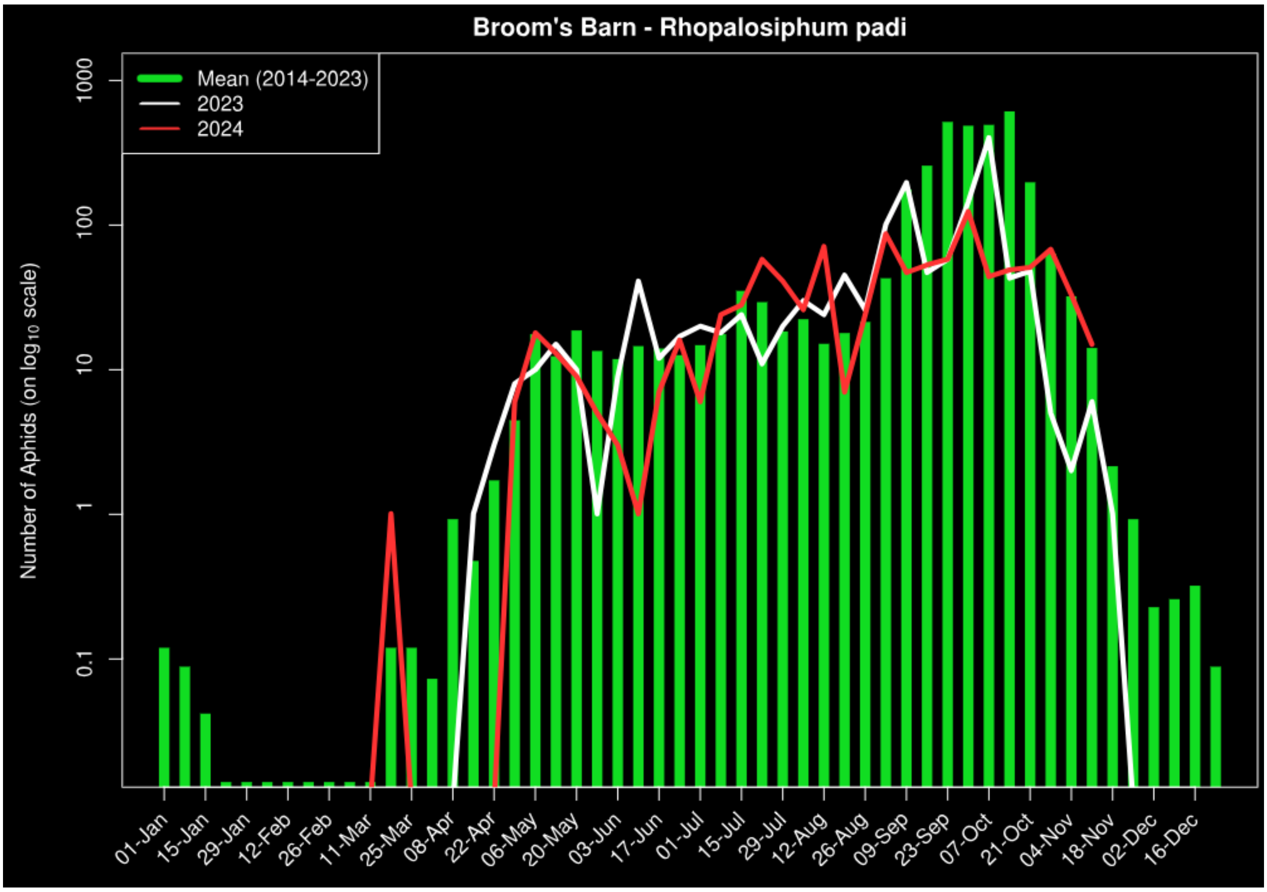

Figure 3.1.8.2. Aphid numbers from the Brooms Barn suction trap. Extracted from the Rothamsted insect survey website 26th of November 2024.

In field aphid and natural enemy monitoring

During sampling of invertebrate's low numbers of aphids were caught in yellow water traps in both fields (table 3.1.8.1 and table 3.1.8.2).

Table 3.1.8.1: Aphid numbers observed in field 1 with the BYDV susceptible variety.

Date	Bird cherry-oat aphid	Grain aphid
03/11/2023	0	0
06/11/2023	0	0
09/11/2023	0	0
16/11/2023	1	0
17/11/2023	0	0
20/11/2023	0	0
24/11/2023	0	0
27/11/2023	0	0
01/12/2023	0	0
04/12/2023	0	0
08/12/2023	0	0
11/12/2023	0	0
16/02/2024	0	0
Grand Total	**1**	**0**

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Table 3.1.8.2: Aphid numbers seen in field 2 with the BYDV resistant variety

Date	Bird cherry -oat aphid	Grain aphid
03/11/2023	1	0
06/11/2023	0	0
09/11/2023	0	0
16/11/2023	0	0
17/11/2023	0	0
20/11/2023	0	0
24/11/2023	0	0
27/11/2023	0	0
01/12/2023	0	0
04/12/2023	0	0
08/12/2023	0	0
11/12/2023	0	0
16/02/2024	0	0
Grand Total	**1**	**0**

In field BYDV assessment

A low number of samples returned positive results for BYDV presence in December in field 1 and no samples returned positive results in April in either field 1 or field 2 (table 3.1.8.3). Visual assessment of the proportion of plants exhibiting BYDV symptoms was made on the 16th of April 2024 (figure 3.1.8.5). Poor establishment of the crops and waterlogging in some areas made BYDV assessment challenging (figure 3.1.8.6), due to many plants showing other symptoms of stress similar to those of BYDV at GS30. The discrepancy between tissue samples and visual assessments could also be influenced by the possibility of other similar viruses present in the region. The Wheat Dwarf Virus (WDF), for example, is known to be present in the UK and can be transmitted by leaf hoppers (*Psammotettix sp*). Although not identified to species several leaf hoppers were caught in the yellow water traps. Any varietal resistance or tolerance to BYDV would not necessarily provide resistance or tolerance to other cereal virus.

Table 3.1.8.3: BYDV tissue sample results from samples collected from field 1.

Sampling point	20th December 2023	9th April 2024
1A	NEGATIVE	NEGATIVE
1B	NEGATIVE	NEGATIVE
2A	NEGATIVE	NEGATIVE
2B	NEGATIVE	NEGATIVE
3A	POSITIVE	NEGATIVE
3B	NEGATIVE	NEGATIVE
4A	POSITIVE	NEGATIVE
4B	POSITIVE	NEGATIVE
5A	NEGATIVE	NEGATIVE
5B	NEGATIVE	NEGATIVE
6A	NEGATIVE	NEGATIVE
6B	NEGATIVE	NEGATIVE

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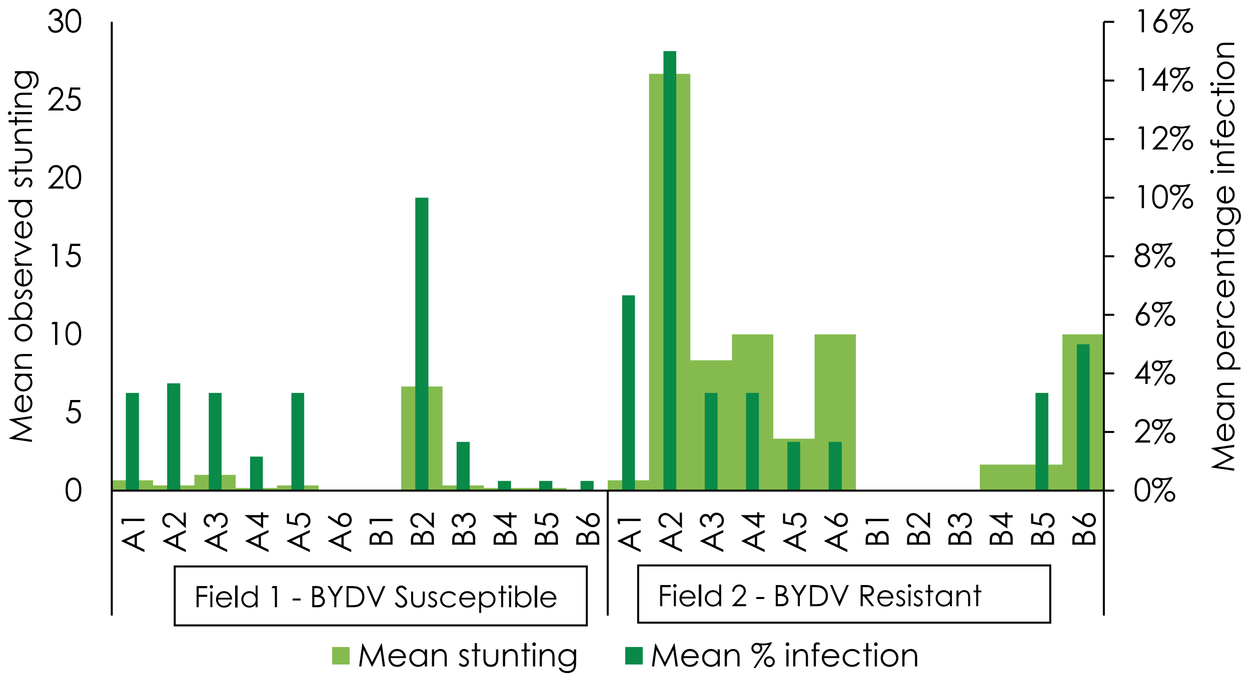

Figure 3.1.8.5: Levels of observed stunting (light green) and the percentage area exhibiting infection (dark green). Labelled with each sampling location and field separately. Assessment carried out on 16th April 2023.

Figure 3.1.8.6: Representative photograph of poor establishment (NIAB, December 2023).

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2023/2024 season Decision support tools

T-Sum: The T-Sum model was run in IPM Decisions based on the crop emerging in both fields on the 17th November 2023. The risk reported was low between emergence and the 6th December 2023, which was the last date of in field aphid observations (figure 3.1.8.7). The T-Sum model was reset at this date, and reported no risk of winged aphids until the end of January 2024. At this time, the decision was made with the host farmer that no applications would be made, and consultation of the model was stopped. Overall, the T-Sum model, supplemented with in field observations, supported no insecticide applications during the 2023-24 season at this location.

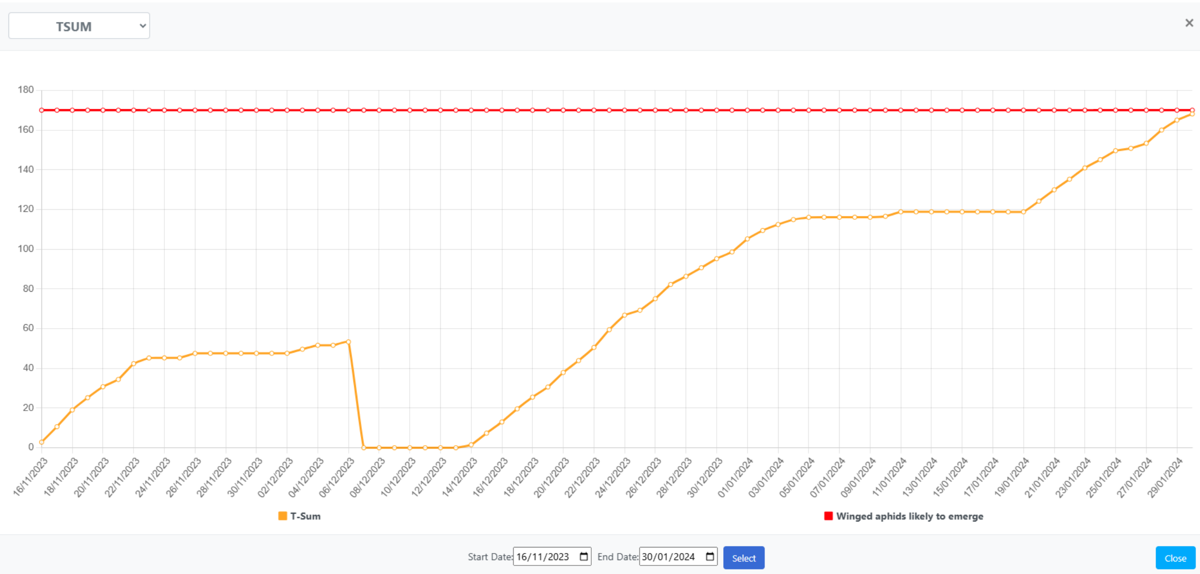

Figure 3.1.8.7: Timeline Output generated from T-Sum giving the 170 threshold (red) and the model output for aphid flight (orange).

ACroBAT: When running the ACroBAT model with the full season's data, the level of risk did not get above "very low", and supported no insecticide applications during the 2023-24 season at this location (figure 3.1.1.8 and figure 3.1.1.9).

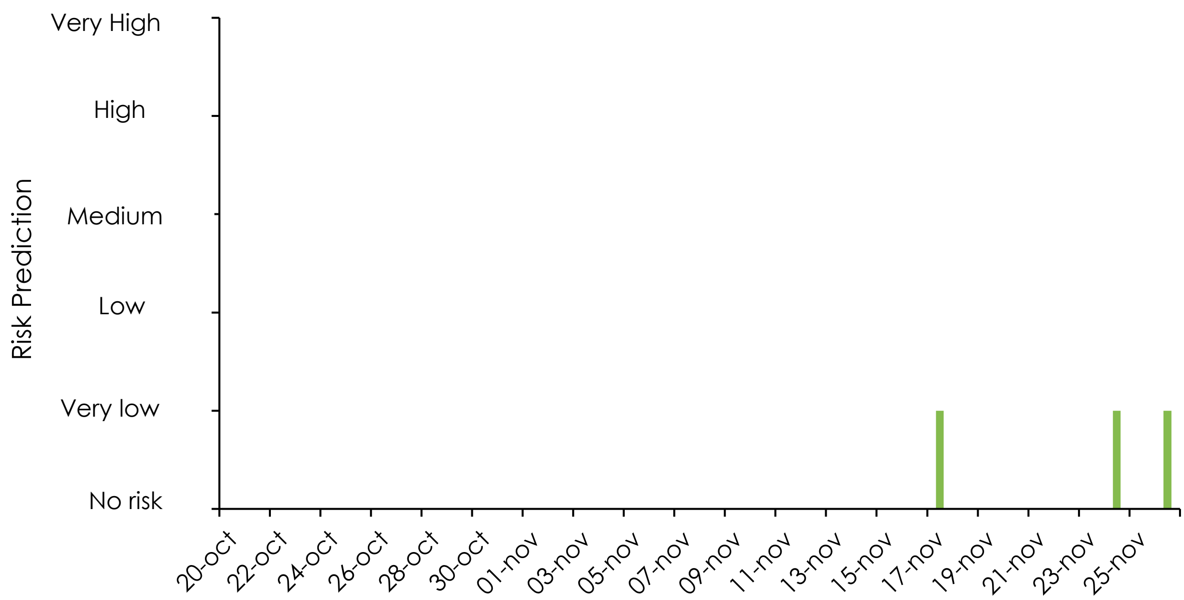

Figure 3.1.8.8: Field 1 risk level as predicted from the ACroBAT model.

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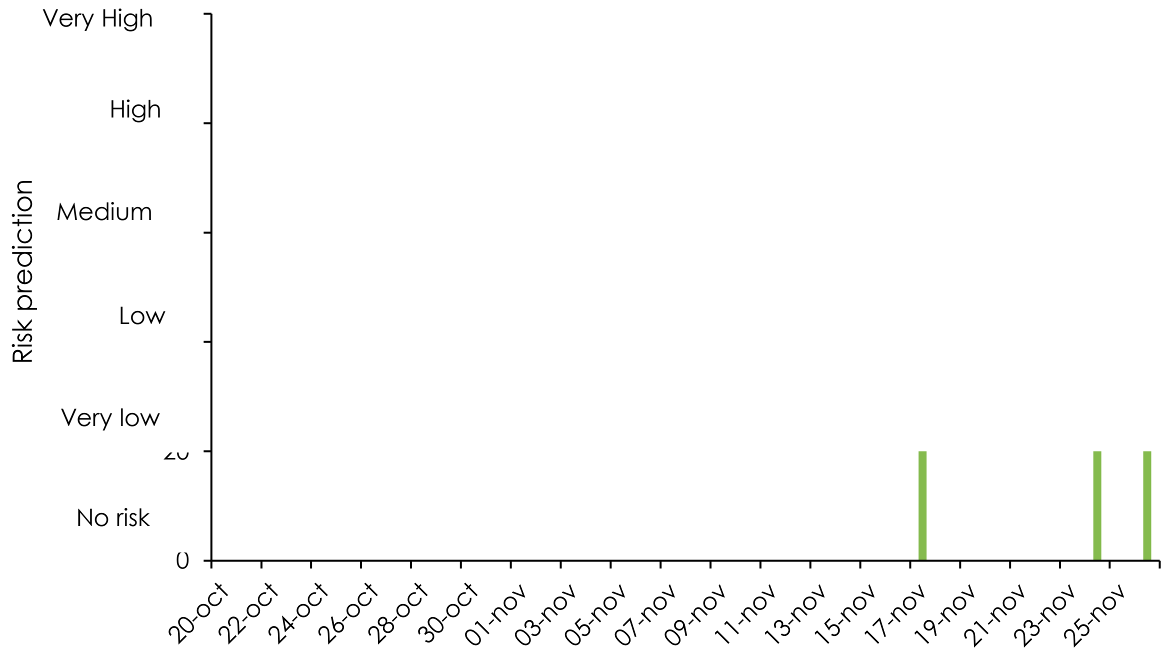

Figure 3.1.8.9: Field 2 risk level as predicted from the ACroBAT model.

Yield

Yield data for both fields were extracted by ADAS and unreliable data points were removed following the ADAS Agronomics approach (figure 3.1.8.10 and figure 3.1.8.12). This created a set of yield data which contained all complete combine runs with equal area to allow comparison within each field (figure 3.1.8.11 and figure 3.1.8.13). Due to the lack of treatment applications the two fields were considered single treatments and the variation in yield from the two fields was examined, however as it is well established that field has a large effect on yield, and in this year establishment of the crops in each of the fields was very different, it was not appropriate to directly compare crop performance of the different varieties between fields.

The average yield in field 1 (cv. Dawsum) was estimated to be 7.94t/ha. Crop establishment was impacted in this crop by the weather, though to a lesser extent than in field 2. The average yield in field 2 (cv. Grouse) was estimated to be 6.39t/ha. There was a history of groundwork by the instalment of a pipe line running through the middle of the field, which impacted the uniformity of the field, highlighting the importance of within field uniformity for detailed interpretation of field level effects. Patchy establishment, partly due to the pipe line and partly due to inclement weather, lead to yield in this field being highly variable. While Grouse is expected to have a lower yield potential compared with Dawsum in the absence of high BYDV pressure, the difference in yield between these two fields is a combination of factors in addition to variety.

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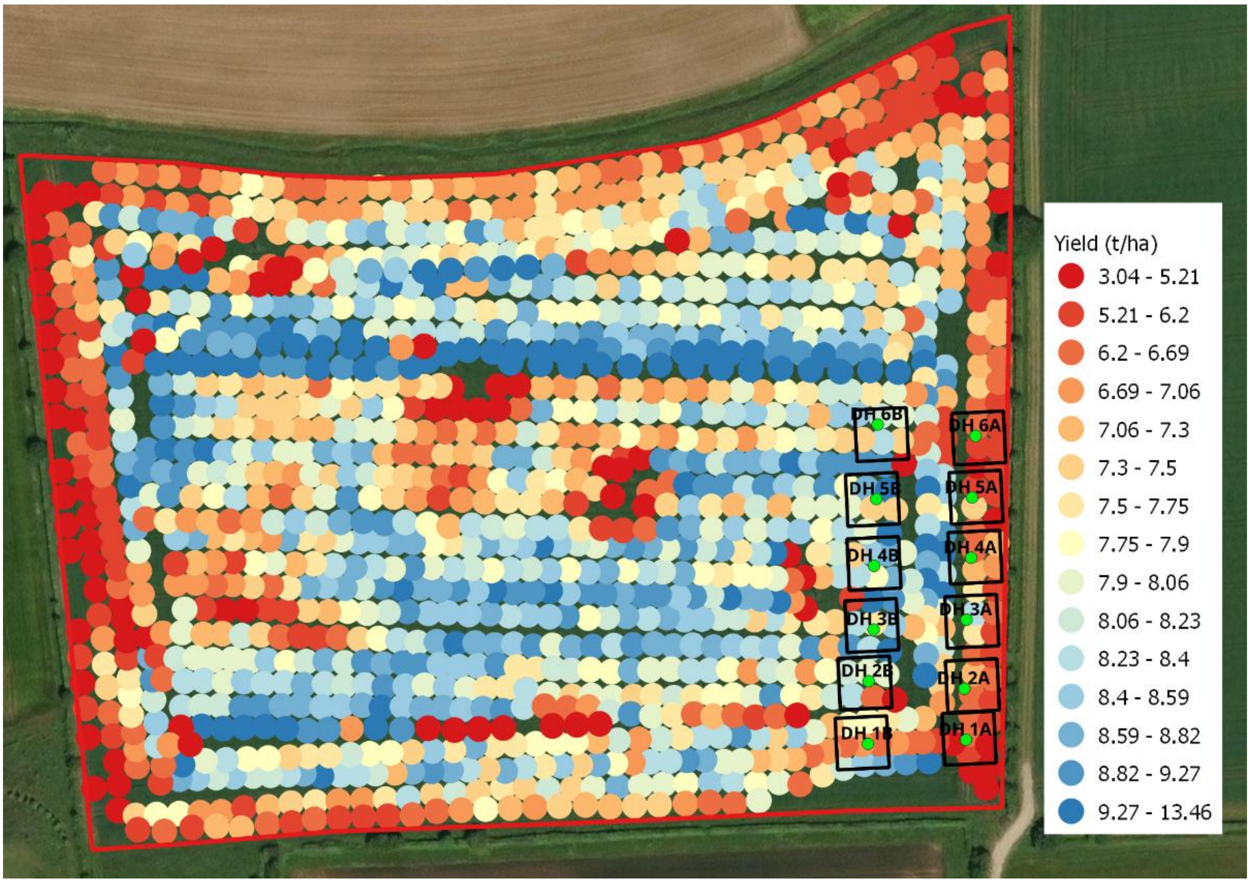

Figure 3.1.8.10: Raw combine yield data mapped for field 1 (cv. Dawsum). The black boxes indicate the locations of the tissue sampling and yellow water trap assessments during the season.

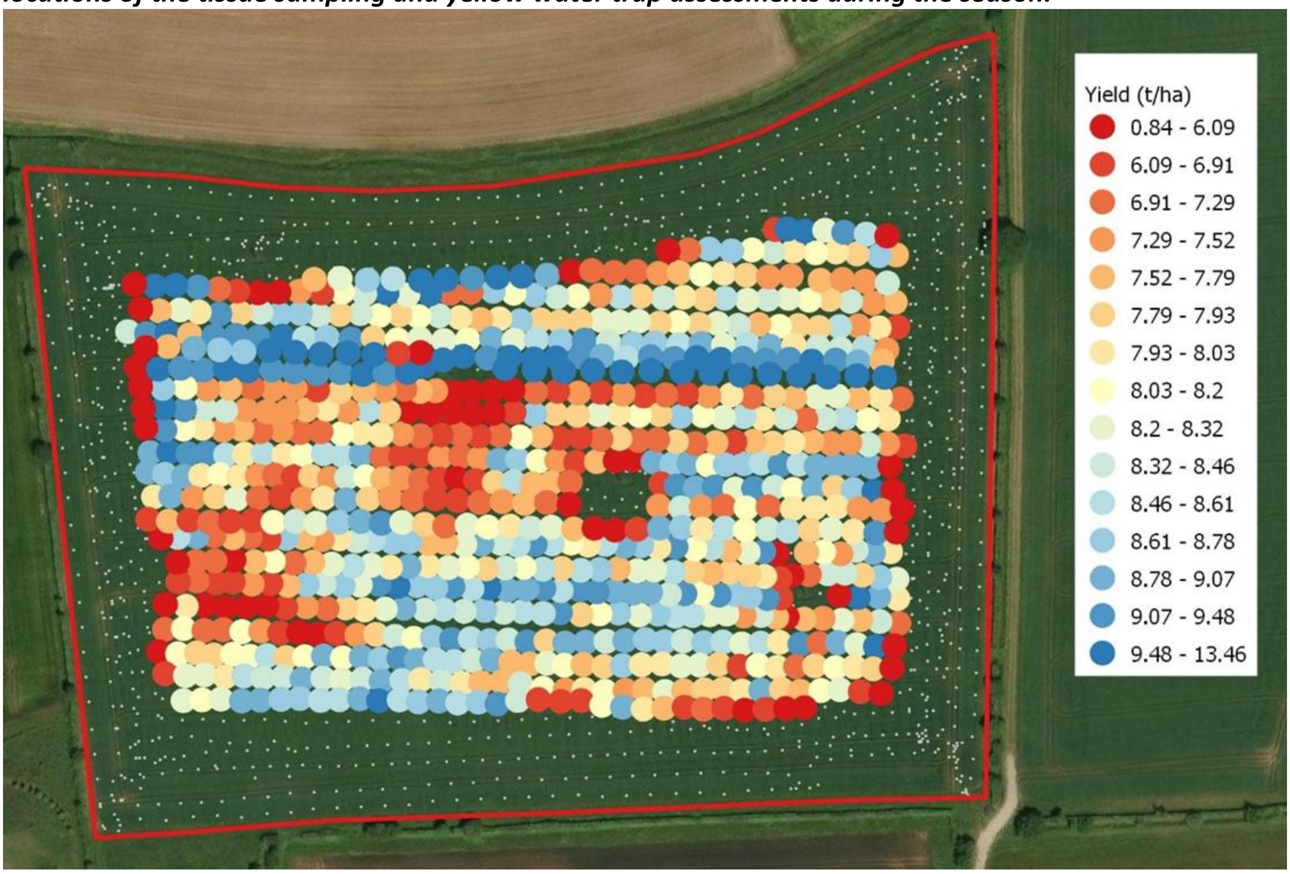

Figure 3.1.8.11: Yield map for field 1 (cv. Dawsum). Showing cleaned data for yield analysis.

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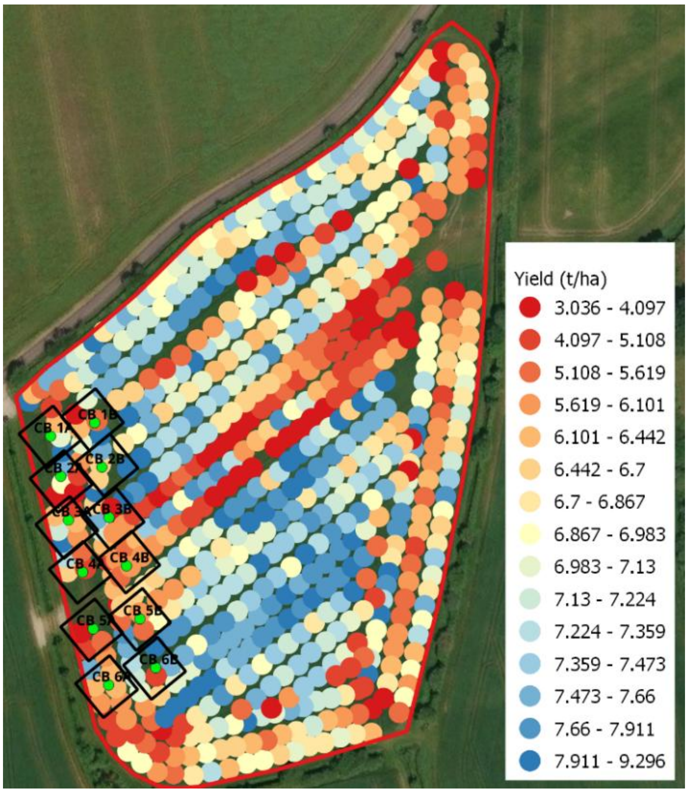

Figure 3.1.8.12: Raw combine yield data mapped for field 2 (cv. Grouse). The black boxed indicate the locations of the tissue sampling and yellow water trap assessments during the season.

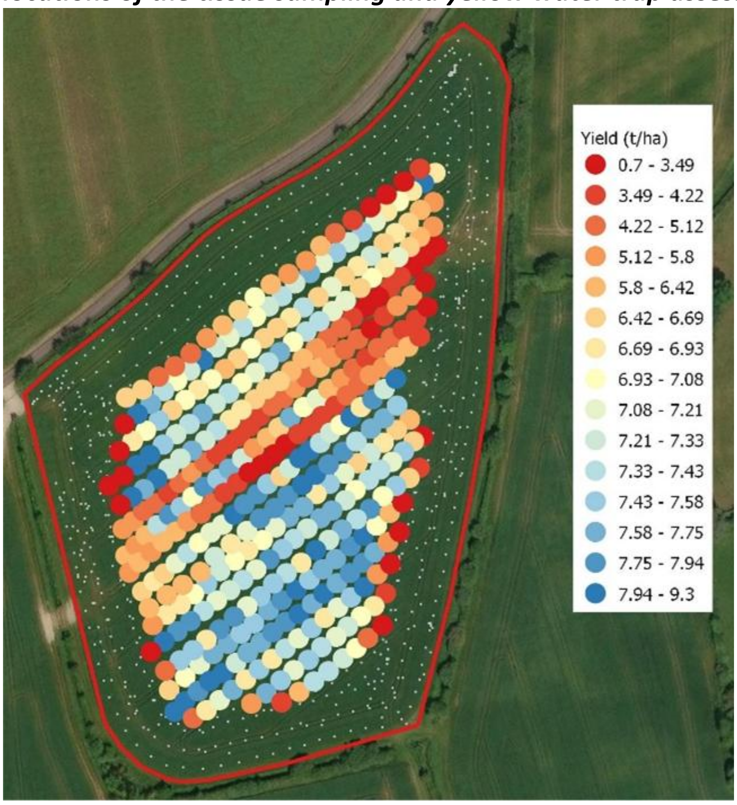

Figure 3.1.8.13: Yield map for field 2 (cv. Grouse). Showing cleaned map for yield analysis. The impact of the previous works to install a pipeline across the field on yield are visible.

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Conclusion

Overall, in the Autumn/Winter of 2023 the aphid population abundance was low in the two fields, while rainfall and soil moisture were high. Both BYDV DSSs and in field observations suggested a low risk of BYDV. Consultation of the DSS supported the decision not to apply any insecticides during the vulnerable period for spread of BYDV. Given the poor travel conditions, this gave the farmer greater confidence in prioritising soil health over BYDV management. The results of tissue analysis and yield demonstrate that this approach was justified, as there was little evidence of widespread BYDV or associated impacts on yield. The yield variation within and between fields observed during the 2023/24 season was most likely due to poor establishment and the variation between fields. Consequently, it is not possible to be certain whether any yield difference is connected to the difference in varietal yield potential or to underlying soil differences. In low aphid pressure and associated low risk from BYDV seasons such as this, the advantage of selecting a "resistant" variety are less evident, though the benefits of using DSS to avoid unnecessary applications is supported. The potential benefits for selecting varieties with resistant/tolerant traits to BYDV may be more pronounced in years or regions of higher pressure. In the UK, the lower yield potential of varieties marketed as resistant may be offset to some extent in fields under Sustainable Farming Incentive (SFI) action CIPM4 (CIPM4: No use of insecticide on arable crops and permanent crops). This action pays farmers £45/ha per year, with the aim that no plant protection products containing an insecticide are applied on an arable crop or permanent crops. Its purpose is to: 1) support an integrated pest management approach by managing crop pests in a more sustainable way, 2) improve water and air quality, and 3) increase biodiversity (DEFRA, 2024).

Methods

Strategies

T-Sum: The T-Sum model was run by ADAS using the IPM Decisions platform.

ACroBAT: The ACroBAT model is functional, but the user interface is not yet complete. As such, manual data entry is required to run the model and extract forecasted risk (table 3.1.8.4). The input data used was compiled from multiple sources. A measure of regional aphid abundance was taken from the Rothamsted Insect Survey's aphid bulletin[3] . ACroBAT requires daily data on regional aphid abundance, whereas the survey data provides total aphids caught over a seven-day period. Data on the proportion of aphids carrying BYDV was generated from work by Rothamsted Research, where samples from four sites in the Insect Survey's suction trap network (Brooms Barn, Suffolk; Hereford, Herefordshire; Starcross, Devon; York, North Yorkshire) were screened for the virus[4]. The proportion of aphids carrying BYDV is calculated from the results on aphids sampled from the Brooms Barn suction trap, being the closest trap to the field sites, at the time of crop emergence. The weather data was extracted from the IPM Decisions Weather Service (data sourced from Open Meteo) to run both the T-Sum and ACroBAT models.

Table 3.1.8.4: Parameters used when running the ACroBAT model.

Model parameter	Attributed value
Seed rate field 1	140kg/ha, 280 seeds/m^2
Seed rate field 2	154kg/ha, 310 seeds/m^2
Drilling date – field 1 (cv. Dawsum)	27/10/2023
Drilling date – field 2 (cv. Grouse)	28/10/2023

[3] https://insectsurvey.com/
[4] https://ahdb.org.uk/knowledge-library/the-uk-aphid-monitoring-network

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Mean Winter temp	6.3°C
Aphid infectivity	18.75%
Treatment costs	£4.5/ha
Yield	9.5ton/ha
Grain value	£195/ton

Assessments

12 yellow water traps were installed in each field and the number of aphids and natural enemies in each trap counted every 3 days from crop emergence until mid-December, resetting the traps at each visit. Each trap acted as the centre point for tissue sampling. Fifteen leaves were collected within a 2m radius around each water trap on the 20th of December 2023 and the 9th of April 2024. Due to adverse conditions, and poor establishment of the crop, tissue samples were not collected from field 2 during the first tissue sampling. Plants were selected at random, to be a representative sample of the area and tested for BYDV by NIAB using ELYSA protocols. On the 16th April 2024, at each sampling point, the percentage of the crop stunted and the percentage of the crop showing clear BYDV symptoms was estimated.

Data analysis

Yield map data was analysed using an R Shiny graphical user interface (GUI) according to the detailed methods described by Marchant et al. (2019). Raw yield data were corrected to 15% moisture content and cleaned to eliminate systematic and random errors. These errors are identified by manual and automatic filtering, removing miscalculations in yield due to the combine running over areas that have already been harvested, changes in speed of harvest across the tramline, harvest rows where the swath width was less than a full header width etc. Rows of data points were straightened to refine the coarse geo-referencing quality provided by the harvester. Following this, a time shift was applied to account for the delay between the crop being cut and the grain yield being recorded by the monitor (Muhammed et al., 2014). Without access to the novel analysis software used in this here, comparisons between strategies could be conducted using a weighbridge.

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3.1.9. IPMWORKS: Using Decision Support System to improve Barley Yellow Dwarf Virus (BYDV) management in the Netherlands

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2. ADAS, England

Summary

Barley yellow dwarf virus (BYDV) affects a wide range of cereal crops worldwide. This challenging virus is introduced to crops and spread by aphid vectors. Infection causes stunted plants and chlorosis which significantly reduces yield. Control relies on the use of pyrethroid insecticides; however, these are non-selective chemicals, harmful to invertebrates and thought to impact aquatic ecosystems. Overuse of this insecticide is also leading to resistance development in aphid populations. Integrated pest management is therefore vital to enable control of this disease, while minimising chemical inputs. In this comparison, aphid populations were monitored in two fields of winter wheat in the Netherlands in autumn 2023 and the T-sum model used to guide insecticide applications. The T-sum results for these fields was also compared to a field which was drilled slightly later to demonstrate the impact of sowing date. Although aphids were present in both fields, high rainfall prevented the application of insecticide when the T-sum was reached. This highlights the importance of integrating different control strategies to reduce BYDV risk, not just relying on chemical applications alone.

Introduction

Barley yellow dwarf virus (BYDV) is a challenging disease that affects wheat, barley, oat, rye and triticale crops worldwide. Symptoms include discolouration due to chlorosis of the leaves and stunting of the crop which can result in significant reductions to crop yields (Walls et al. 2019). BYDV is transmitted by aphid vectors such as *Rhopalosiphum padi, Sitobion avenae* and *Myzus persicae*. Infected aphids feed on recently drilled crops, introducing the disease as a primary source of inoculum. BYDV is then spread through the crop by aphids feeding on the infected plants and transmitting the virus to other plants within the field. As a result, symptoms often occur in patches as disease spreads from the initial infection point. Since the European Union ban on neonicotinoid seed treatments from 2019, control of BYDV has relied on the prophylactic application of pyrethroid insecticides. As the only chemical method of control, resulting in widespread use of pyrethroids, multiple forms of resistance and tolerance have started to develop in aphid populations, reducing efficacy of pyrethroid sprays (Namara et al. 2024). There are also concerns about the impact of pyrethroid insecticides on non-target invertebrates and aquatic ecosystems (Ranatunga et al. 2023). To reduce to risk of resistance development and impact on the environment, it is vital that BYDV is controlled in an integrated approach to reduce reliance on pyrethroids.

It is well known that drilling later in the season can help to reduce the impact of BYDV, as crops emerging earlier in the season, while conditions are more conducive to aphid flight and breeding, will be at much higher risk of infestation by aphids carrying the virus, than those that emerge later (Kennedy and Connery, 2001). Application of insecticides can also be improved with the use of a decision support system (DSS). To help growers with the timings of these applications the Agricultural and Horticultural Development Board (AHDB) in the UK developed a T-sum model (AHDB, 2024). This tool has been made available to growers across Europe by inclusion on the IPM Decisions platform (IPM Decisions, 2024). This model predicts when the second wingless generation of aphids, responsible for secondary BYDV spread, will appear in the crop. This is approximately when 170-degree days have accumulated after a baseline of 3°C. The model will highlight

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when this is reached and suggest an insecticide application is required, if aphids are present in the crop. By using a decision support system, growers can have more confidence in not applying insecticides where risk of infection is low, in later sown crops and during cold winters, and ensure where insecticides are required, applications are targeted to optimise control.

In this comparison, two fields of winter wheat which emerged mid-October 2023 in the south of The Netherlands, were monitored for aphids during the autumn and the T-sum model used to guide the grower on whether an insecticide application was required. The results of the T-sum model for these fields were also compared to a field that emerged slightly later to demonstrate the impact of sowing date.

Results

Two fields located in the Netherlands were monitored for aphids.

Field 1:

The winter wheat crop emerged on the 18th October 2023. The crop was monitored on the 27th October and 9th November, on both occasions aphids were seen in the crop (figure 3.1.9.1). The T-sum model on the IPM Decisions platform reached 170 accumulated degrees over 3°C since crop emergence on the 6th November, which is associated with the emergence of winged aphids that act as vectors for BYDV (figure 3.1.9.2). As aphids were found in the crop, the risk of BYDV was high and so an insecticide application was permitted. However, due to very wet ground conditions, this application could not be applied. The hub coach was concerned that as no insecticide was applied and aphids present, there would be BYDV symptoms in the spring, however there were no signs of infection in the crop. Therefore, the aphids seen must not have carried the disease.

Figure 3.1.9.1: Images taken of the crop on the A. 27th October and B. 9th November

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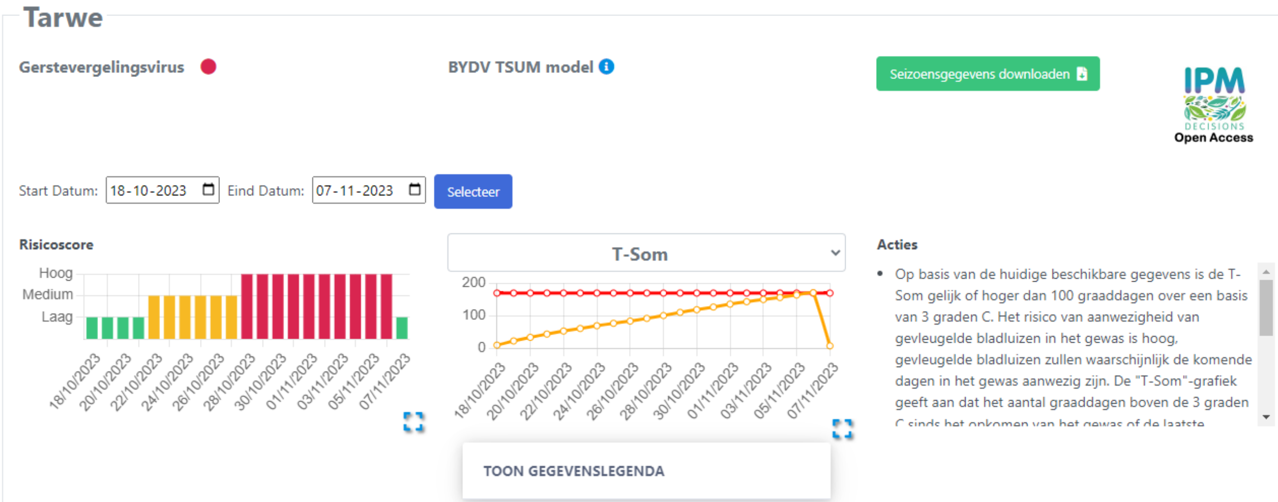

Figure 3.1.9.2: Output from IPM Decisions showing that T-sum has been reached in a crop that emerged on the 18th October.

Field 2:

This winter wheat crop emerged on the 16th October 2023. The crop was monitored on the 31st October and 27th November, on both occasions aphids were seen in the crop (figure 3.1.9.3). The T-sum model on the IPM Decisions platform reached 170 accumulated degrees over 3°C since crop emergence on the 3rd November, which is associated with the emergence of winged aphids that act as vectors for BYDV (Figure 3.1.9.4). As aphids were found in the crop, the risk of BYDV was high and so an insecticide application was permitted. However, due to very wet ground conditions, this application could not be applied. The hub coach was concerned that as no insecticide was applied and aphids present, there would be BYDV symptoms in the spring, however there were no signs of infection in the crop. Therefore, the aphids seen must not have carried the disease.

Figure 3.1.9.3: Images taken of the crop on the A. 31st October and B. 27th November

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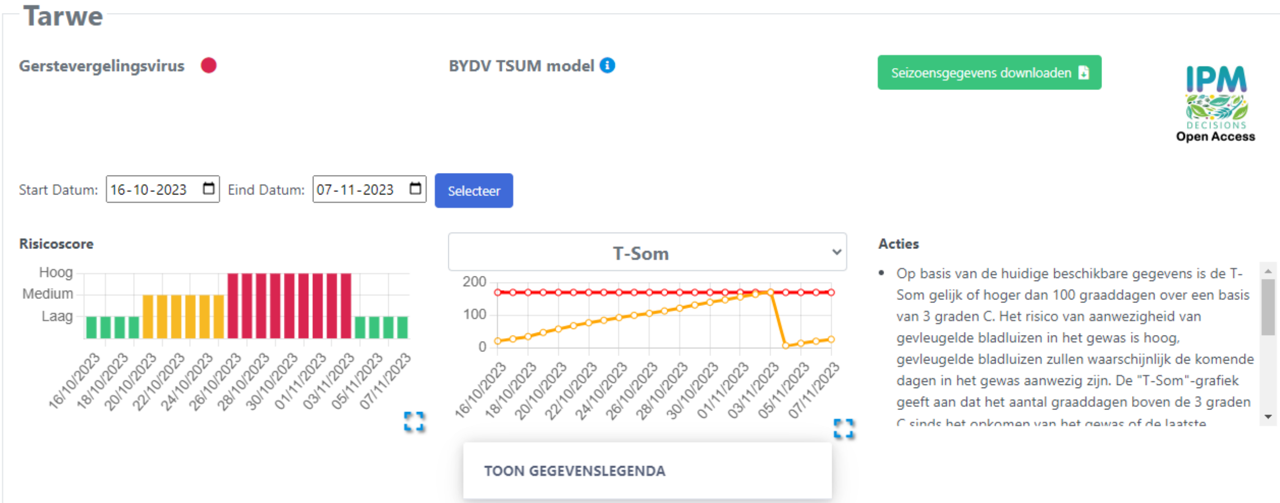

Figure 3.1.9.4: Output from IPM Decisions showing that T-sum has been reached in a crop that emerged on the 16th October.

Impact of later drilling on the T-sum

The emergence date from a third field was input into the T-sum model. This crop didn't emerge until the 27th October and so T-sum wasn't reached until mid-November as temperatures were cooler (Figure 3.1.9.5). The risk of BYDV would therefore have been lower in this crop.

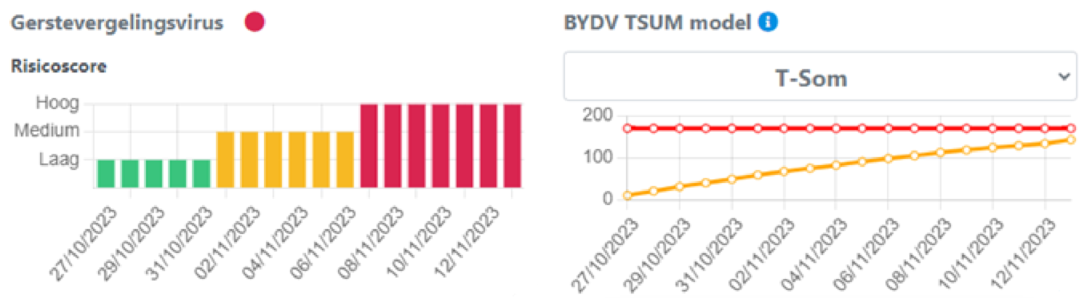

Figure 3.1.9.5: Output from IPM Decisions showing that T-sum has been reached in a crop that emerged on the 27th October.

Conclusion

BYDV, is a challenging disease to control. Transmitted to cereal crops by aphid vectors, as with most viruses by the time symptoms are expressed it is much too late to control. The development of decision support systems to guide the requirement and optimal timing of insecticide applications is vital, to prevent repeat, prophylactic applications of chemicals that are harmful to the environment. In this comparison although aphids were present and so an insecticide application was permitted once T-sum was reached, ground conditions were too wet for machinery to travel the field. In this case no BYDV symptoms were seen in the spring suggesting that that the aphids were not carrying BYDV. It is also hypothesised that the wet conditions may have prevented the aphid population from growing and therefore limited their spread within the crop. This highlights that while the development of decision support systems has improved BYDV control and will have reduced unnecessary insecticide usage, if insecticide applications cannot be applied due to poor weather conditions the crop is at risk of substantial yield loss. As such it is important to utilise multiple strategies against BYDV in an integrated approach, such as delayed sowing dates where possible and the use of BYDV resistant or tolerant varieties where available.

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Methods

Strategies

This comparison was designed to demonstrate the impact of sowing date and use of a decision support (DSS) system for control of BYDV in wheat. Two fields were selected and monitored for aphids in the autumn, the requirement for an insecticide application was supported with the use of the T-sum model. The emergence date of a third field was used to look at the impact of sowing date on the risk of BYDV.

Application of insecticides

The application of insecticides in each field to control aphids was based on the BYDV DSS (T-sum) and in field monitoring to see if aphids were present. Note that the BYDV DSS recommends an application when T-sum is reached (accumulated daily air temperature of 170), resetting after an insecticide application. This helps to guide timing of applications. The first application being the most important. Whether or not to spray when T-sum is reached should be decided based on whether aphids are seen in the field.

Accessing the BYDV model:

- Register on the IPM Decisions website https://www.platform.ipmdecisions.net/
- Instructional videos can be found here: https://www.youtube.com/channel/UC4PnJR7kwPyPKVhEGxCBRKg
- Add each field into the platform as a different farm, using the field as the farm location. Weather data can take a few hours to calibrate.
- Add DSS to each field location individually. Select the crop: winter wheat or barley and DSS for BYDV.
- On the DSS Use platform, parameters of the model can be edited by clicking the BYDV button.
- The date of crop emergence must be included. To obtain accurate risk predictions it is essential to click on the 'Edit parameters' button, enter the crop emergence date then click the 'Save' button. These estimated dates can be updated during the season as growth stages are reached.
- Adding information on BYDV spray dates is also vital for the model. This is again done in 'Edit parameters'. Clicking on 'Save' will keep the spray dates entered.
- Make sure to do this separately for each field as a separate farm.

Aphid Monitoring

For each field, in 10 places evenly distributed across the field, 10 plants were checked for any aphids (100 plants in total per field), carefully checking the base of the plant and just under the soil surface. Bird cherry-oat aphids can sometimes be found on the main shoot at or just below soil level. Assessments completed one week after emergence and followed by a second assessment three to four weeks after emergence.

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3.1.10. IPMWORKS: Using a mechanical weeder in spring barley in England

Authors: Dearlove, E.[1] and Francis, C.[1]

1. ADAS, England

Summary

Mechanical weeders show great potential for managing weeds whilst reducing chemical herbicide inputs in arable agriculture. The System Cameleon employs precision drilling and cultivation between rows to target and remove weeds, offering a promising alternative to traditional herbicide applications. In this comparison in 2023, a field near Newcastle, England, was divided into alternating zones where the mechanical weeder and conventional weed control strategies were applied. A simple assessment of percentage weed cover in each strategy was carried out to evaluate the impact of each strategy. There were no clear differences in weed cover between the System Cameleon drill incorporating mechanical weeding and comb cut for weed control, and the two different strategies utilising herbicides. The use of mechanical weeding alongside other weed management strategies in an integrated approach to weed management will reduce reliance on herbicides, contributing to sustainable and effective weed management in arable agriculture.

Introduction

In the context of modern agriculture, the primary objective is to maximize crop yield while minimizing associated costs. Among various factors that contribute to yield loss, weeds pose a significant threat through competition with crops, leading to reduced yield and grain quality and increased control expenses (Oerke, 2006). Barley (*Hordeum vulgare*) is the fourth major cereal produced globally after wheat, maize, and rice. Barley is tolerant to several abiotic and biotic conditions; nonetheless, weed infestations can significantly reduce its yield and productivity (Naeem et al., 2020 & 2021, Diyanat and Baziar, 2023).

The over-reliance on chemical control has led to a number of environmental and agronomic concerns. The application of herbicides, combined with other changes in farmland management, is leading to the reduction of non-weedy species and having impacts on farmland biodiversity and ecosystem function (Moonen & Bàrberi, 2008; Storkey *et al*., 2012). Furthermore, the escalating issue of herbicide resistance in various weed species, driven by the extensive use of a limited set of active ingredients, is a critical challenge in modern agriculture (Heap, 1997; Moss *et al*., 2011). In the United Kingdom, herbicide resistance has been reported on at least 16,000 farms across 34 counties, highlighting the widespread nature of this problem (Moss *et al*., 2011). Additionally, stringent herbicide regulations in the European Union, coupled with the scarcity of new modes of action, increase the risk of resistance development to the remaining herbicide products (Duke, 2012). In response to these challenges, mechanical weeders have emerged as a pivotal component in effective weed management within arable agriculture. These devices play a crucial role in reducing reliance on chemical herbicides, offering several advantages inherent to mechanical weeding technologies. In recent years, there has been a growing interest in adopting precision drilling and cultivation techniques to specifically target and remove weeds while minimizing disruption to the surrounding crop.

Precision drilling relies on advanced technologies, such as GPS-guided machinery and automated seed placement systems. This enables farmers to plant seeds with utmost accuracy, optimizing the distribution of crops and creating an environment that hinders weed growth. With the use of precision cultivators and robotic systems, farmers can selectively target and remove weeds within the space between crop rows, without disturbing the crop. The most common mechanical weeding strategy in organic systems is weed harrowing, which has been shown to prevent weeds from being a limiting factor of crop productivity while maintaining a rich flora, promoting biodiversity (Armengot et al. 2013). Achieving optimal weed control with

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weed harrowing requires careful consideration of the timing and machinery settings, requiring precision to target very small, cotyledon-staged weeds and as such repeated treatments with short intervals are often necessary (Rasmussen *et al.,* 2010). In row crops with straightforward inter-row operations, inter-row cultivation using steerage hoes is a widely adopted practice. The weeding device typically consists of a goosefoot share, providing a cutting action that can effectively remove inter-row weeds, unless soil conditions are wet or the weeds have grown too large to be controlled (Melander *et al.,* 2005). While its primary application is against annual weeds, inter-row hoeing can also exhibit some efficacy against perennials (Graglia *et al.,* 2006). Although it may not entirely eradicate perennial weed problems, it disrupts belowground propagules, stimulates re-sprouting, and hampers the regenerative capacity of perennial weeds by interrupting translocation of photosynthetic assimilates to roots and rhizomes (Graglia *et al.,* 2006). According to research by McCollough et al. 2019, compared to sowing 16.5cm single rows, band sowing with hoeing reduced surrogate weed density on average by 45%.

The System Cameleon, is designed to integrate a seed drill with mechanical weeding capabilities. It's inter-row mechanical weeding technique allows it to operate between crop rows post-emergence and replacing multiple machines by also introducing novel field applications like inter-row fertilization. As a drill, it ensures precise line spacing during drilling, facilitating closer inter-row hoeing than conventionally possible. This comparison in 2023 aimed to explore the impact of drilling, mechanical and herbicide treatment on weed suppression through three distinct strategies in a crop of spring barley. Strategy 1 involved using the System Cameleon to drill the crop in addition to a conventional herbicide program. In Strategy 2, the System Cameleon was employed for drilling, followed by harrowing and comb cutting to manage weeds. Strategy 3 utilized a conventional drill & herbicide spray programme. This comparison was completed in collaboration with Newcastle University.

Results

A weed assessment was carried out in July 2023, within a 1m^2 quadrat, the percentage area containing weeds was estimated, in 20 places per strategy. Crop establishment across the field was variable and patchy in places, as a result weed burden was high due to poor competition from the crop. Differences in weed cover between the three strategies were small and not statistically significant (table 3.1.10.1).

Table 3.1.10.1: Treatment of barley in an 'in-field' comparison of mechanical and chemical weed control options and average percentage weed cover observed in July 2023.

Strategy	**Average weed cover (%)**
Cameleon drill and comb cut	8.9
Cameleon drill and herbicide spray	14.1
John deere and herbicide spray	11.9
ANOVA P-Value	*0.425*

Conclusions

In this comparison there were no clear differences in weed cover between the System Cameleon drill incorporating mechanical weeding and comb cut for weed control and the two different strategies utilising herbicides. The application of herbicides has negative impacts on farm biodiversity and overuse has led to the development of resistance, reducing herbicide efficacy. It is therefore vital that use of herbicides is reduced by combining weed control methods in an integrated approach to weed control. Mechanical weeding such as weed harrowing and inter-row hoeing shows great potential in managing weeds and as such, precision cultivators with mechanical weeding capabilities and robotic weeders have been developed and are increasing in popularity. Utilising such systems will reduce reliance on herbicides, contributing to sustainable and effective weed management in arable agriculture.

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Methods

Treatments

This comparison was designed to investigate the effect of mechanical weeding on weed suppression (table 3.1.10.2).

Table 3.1.10.2:

Strategy 1:	System Cameleon drilled crop plus conventional herbicide programme
Strategy 2:	System Cameleon drilled, harrowed and comb cut to control weeds.
Strategy 3:	Conventional drill & herbicide programme

Satellite Imagery

The normalized difference vegetation index (NDVI), a spectral reflectance index indicating a combination of canopy size and greenness on a scale from 0 to 1, was checked at the start of the comparison. Satellite NDVI images were obtained from www.datafarming.com.au to illustrate the underlying variation in the field. The colour scale differed among images but consistently ranged from red (low) through orange, yellow, and green to blue (high). Observations revealed some variation from left to right in the field, but tramlines and strategies were designed to intersect this variation, minimising the impact of field variation on the results.

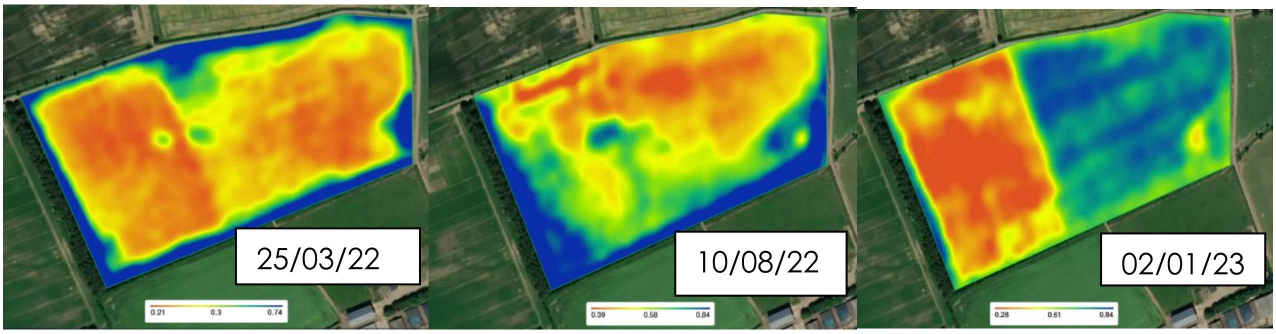

Figure 3.1.10.1: Three NDVI images of the field prior to starting the comparison.

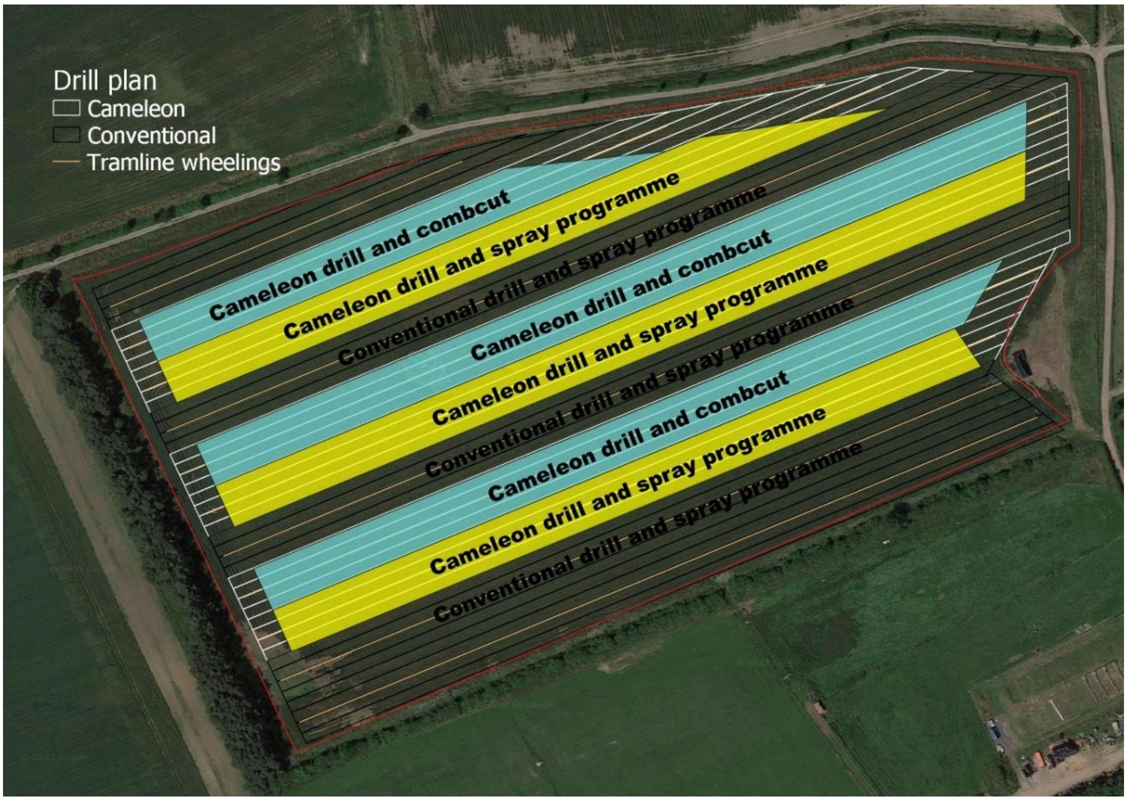

Figure 3.1.10.2: The locations of strategies 1, 2, and 3 based on a tramline width of 24m.

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Design

Field layout is shown in figure 3.1.10.2. Strategies were replicated across the field to improve the reliability of the data.

Weed assessment

An assessment was conducted in July 2023. Weed cover was assessed at 20 points per strategy. The assessment points were spread across the field, to give a representative result. For each quadrat the percentage weed cover of the quadrat was estimated.

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3.1.11. IPMWORKS: Using sulphur for disease control in wheat in England

Authors: Dearlove, E.[1] and Francis, C.[1]

1. ADAS, England

Summary

Minimum tillage (min-till) and direct drilling are conservation tillage practices that involve disturbing the soil less compared to conventional tillage methods, decreasing carbon dioxide emissions by reducing soil disturbance, preserving soil structure and organic matter and reducing erosion. However, different tillage systems may impact disease development. No-till or reduced tillage practices can create a more stable and diverse soil environment, promoting beneficial microbial communities that suppress certain soil-borne pathogens. But reduced tillage may also enhance the survival of certain pathogens that thrive in crop residues. In this comparison, a field of winter wheat near Stockfield, England in autumn 2022 was cultivated using one of three strategies: plough, min-till or direct drill. Within each of these strategies, one of four disease control strategies was applied; 1) a standard application of fungicides at key growth stages throughout the season; 2) and 3) applications of sulphur in replacement of one or more of the standard chemical fungicides usually applied and, 4) no fungicide treatment. A disease assessment was conducted in July across the field. Disease presence, species and severity was noted as well as green leaf area for flag leaves and eventual leaf layer 2. Subsequently, winter wheat was harvested using a yield mapping combine harvester, enabling precise yield measurements, and facilitating direct comparisons between the strategies. There was no clear difference in septoria severity or yield between the three different cultivation strategies. All three fungicide strategies reduced septoria severity and increased green leaf area and consequently yield compared to the untreated, demonstrating the potential of sulphur-based fungicides for control of septoria in wheat.

Introduction

Wheat stands out as a critical source of calories for both humans and livestock worldwide, contributing approximately 35% to meet the global demand (Senapati et al., 2020). However, the prevalence of plant pathogenic fungi significantly diminishes wheat yields. In 2019, nearly 22% of the global wheat yield succumbed to fungal diseases (Savary et al., 2019). Notably, diseases such as leaf rust, fusarium head blight, septoria tritici, stripe rust, spot blotch, tan spot, and powdery mildew emerge as major threats to crop health (Kayim et al., 2022). Currently, control of fungal disease is maintained through the use of chemical fungicides, however overuse has led to the development of resistance, particularly in septoria populations, reducing fungicide efficacy. To maintain the effective life of current chemistry, the number of applications of an active ingredient should be limited and they should only be applied in mixture with effective fungicide partners and multi-site fungicides. Disease pressure should also be reduced by utilising cultural disease control strategies such as varietal resistance, crop rotation and sowing date in an integrated pest management strategy (Dooley et al. 2016).

Multisite fungicides target multiple sites within fungal cells, reducing the likelihood of resistance development compared to single-site fungicides (Cools and Fraaije, 2008). Chlorothalonil was a widely used multi-site, however it was banned in the EU in 2019 due to concerns of its carcinogenic properties, risk to fish and amphibians and contamination of groundwater (Kiefer et al. 2020). Since then, folpet has been used. More recently sulphur has been registered as a multi-site fungicide in the UK, although it is probably one of the oldest pesticides, it is once again being used on a wide range of crops largely for the control of powdery mildew (Williams and Cooper 2004). Sulphur inhibits various stages of fungal development, including spore

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germination and mycelial growth (Cohen, 1987). Additionally, Sulphur's rapid degradation and low toxicity to non-target organisms contribute to its environmental suitability (Dik et al., 2019). It is also approved for use in organic systems.

Conservation tillage practices involve minimizing soil disturbance, promoting residue cover, and enhancing organic matter content, creating a conducive environment for beneficial microorganisms (Derpsch et al., 2014). Research on the impact of tillage on the foliar disease septoria has produced variable results. Leaving large amounts of wheat stubble and debris on the soil surface can increase the likelihood of a septoria epidemic if conditions are favourable, particularly where wheat cropping intervals are low (Eyal et al. 1987). Reduced-tillage systems including no-tillage and strip tillage have well-known benefits for conserving and improving soils, protecting vulnerable crops from extreme weather events, and reducing labour and fuel costs associated with full-width inversion tillage (Franzluebbers 2005; Parsch et al. 2001; Pesant et al. 1987; Spargo et al. 2008). Conservation tillage has been shown to conserve seed bed moisture and total soil water, proving beneficial in areas of low rainfall (Shubbulakshmi et al. 2009). Soil tillage affects both the profitability and sustainability of cropping systems. Minimum-tillage and no-tillage systems are promoted because research has shown that these systems may reduce production costs and improve biological sustainability when compared to conventional systems, in which mouldboard and disc ploughs are used. However, responses to different tillage systems may differ for different crops as well as different soil and climatic conditions (Agenbag, 2012).

In this comparison, located in England in autumn 2022 through to 2023, integrated use or replacement of chemical fungicides with the organic approved multi-site sulphur was demonstrated under different cultivation strategies. A field of winter wheat was cultivated using one of three strategies: plough, min-till, or direct drill. Within each of these strategies, four disease control strategies were applied; 1) a standard application of fungicides at key growth stages throughout the season; 2) and 3) applications of sulphur in replacement of one or more of the standard chemical fungicides usually applied and, 4) no treatment with fungicides. This comparison was completed in collaboration with Newcastle University.

Results

Disease

There were four fungicide strategies within each cultivation strategy:

1. Untreated = Untreated with fungicide
2. Standard = Standard fungicide programme with three fungicide applications (approximately at GS32, GS39 and GS65), including folpet at GS32 and GS39.
3. Combination = Standard fungicide programme with three fungicide applications (approximately at GS32, GS39 and GS65), replacing folpet with a sulphur product.
4. Sulphur = A sulphur-based programme with sulphur applied at GS32 and GS39 and a standard GS65 application.

There was no clear difference between cultivation strategies in septoria severity on the flag leaf, with an average of 36.8% severity for ploughing, 32.3% for min till and 29.2% for direct drill when averaged across fungicide strategy. In both the direct drill and min till cultivation strategies, the untreated had the highest septoria severity, both the standard and combination programmes achieved the lowest septoria severity values and were very similar to each other, while the sulphur programme achieved a more modest reduction in septoria severity compared to the untreated. In the plough cultivation strategy, the standard, combination and sulphur programmes all appeared to have slightly higher disease severity than the untreated (figure

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3.1.11.1). This is unlikely to be a true effect and could be because the untreated had very little green leaf area remaining in this cultivation strategy, making it difficult to accurately assess septoria severity and as such septoria severity has been underestimated in this programme.

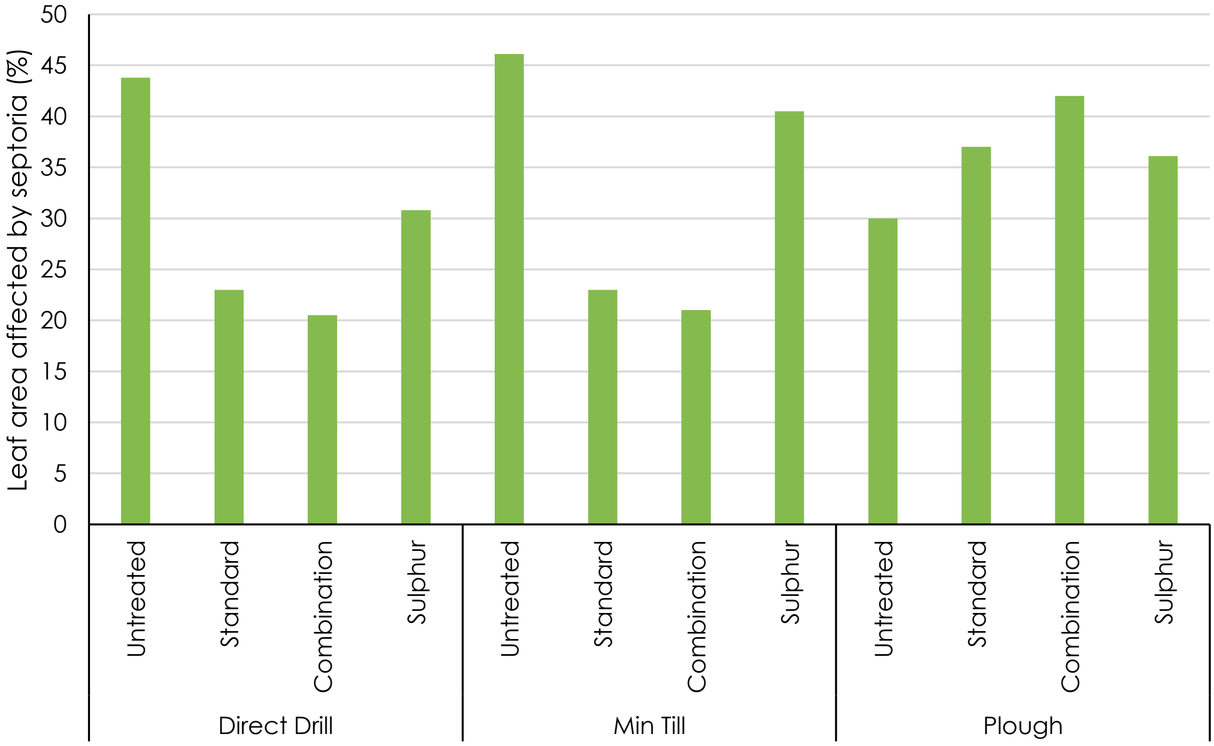

Figure 3.1.11.1: Percentage of flag leaf with septoria symptoms during assessment of wheat in comparison of cultivation and fungicide treatment strategies.

Both cultivation strategy and fungicide treatment strategy had an impact on the amount of green leaf area (GLA) remaining on the flag leaf and eventual leaf 2 (EL2). When averaged across fungicide strategies, direct drilling had 58.8% GLA on the flag leaf and 33.1% on EL2, which was similar to min till with 46.8% on the flag leaf and 25.3% on EL2, both of which were much higher than the ploughed area at 29.1% on the flag leaf and 3.4% on EL2. This suggests that the crop within the ploughed area senesced earlier than either the direct drill or min till. As the cultivation strategies are not randomised across the field, it is difficult to know whether this is a true effect or a consequence of a split in the field management between the east and west sides of the field prior to 2019. When comparing fungicide strategies in all three cultivations, on both leaf layers, the standard and combination strategies tend to be similar where data has been collected, achieving the highest GLA values. The sulphur programme also achieved an increase in GLA on the flag leaf and EL2 compared to the untreated in all three cultivation strategies, except for leaf 2 in the plough (figure 3.1.11.2).

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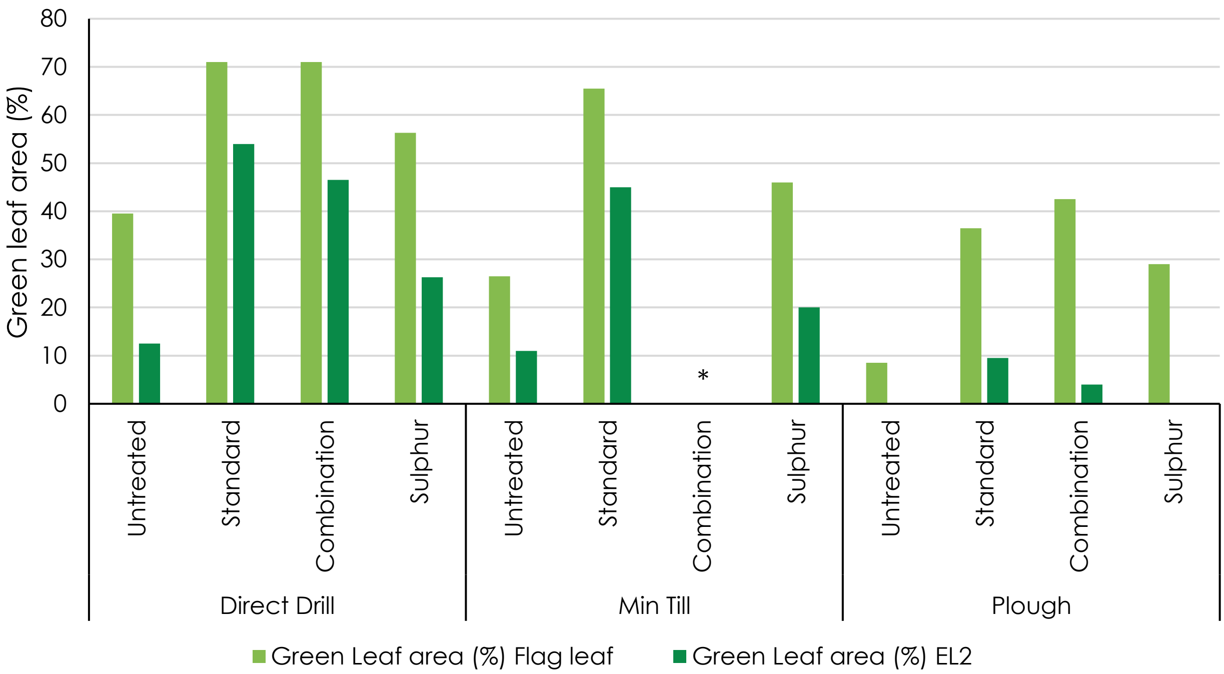

Figure 3.1.11.2: Percentage of flag and Eventual leaf 2 (EL2) green leaf area during assessment of wheat in comparison of cultivation and fungicide treatment strategies. *Green leaf area was not assessed for this strategy.

Yield

Agronomics analysis of the yield map data found no significant difference between the three different cultivation strategies when averaged across fungicide strategy (table 3.1.11.1). When comparing the fungicide strategies, averaged across cultivation strategy, all three strategies significantly increased yield compared to the untreated, the highest yield achieved by the combination strategy, and the sulphur strategy performing comparably to the standard strategy (Table 3.1.11.2). The average yield of each individual cultivation and fungicide strategy have also been estimated in table 3.1.11.3. The lowest average measured yield was seen for the direct drilled, untreated strategy which was 8.58t/ha for the areas retained in the yield map analysis. All other strategies, except ploughed untreated, significantly increased yield compared to this.

Table 3.1.11.1: Average yield (t/ha) for the min till area, averaged across fungicide strategy, and the comparison with direct drill and plough with confidence intervals.

Min Till	Direct Drill compared to Min Till			Plough compared to Min Till		
Yield (t/ha)	**Difference in yield**	**SE**	**LSD**	**Difference in yield**	**SE**	**LSD**
10.39	-0.171	0.661	1.295	0.303	0.678	1.33

Table 3.1.11.2: Average yield (t/ha) for the untreated, averaged across cultivation strategy, and the comparison with standard, combination and sulphur fungicide strategies with confidence intervals.

Untreated	Standard compared to untreated			Combination compared to untreated			Sulphur compared to untreated		
Yield (t/ha)	**Difference in yield**	**SE**	**LSD**	**Difference in yield**	**SE**	**LSD**	**Difference in yield**	**SE**	**LSD**
9.00	1.834	0.201	0.394	2.408	0.223	0.436	1.965	0.204	0.4

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Table 3.1.11.3: Average yield for each cultivation and fungicide strategy (t/ha).

Cultivation	Treatment	Yield
Direct Drill	**Untreated**	8.58
	Standard	10.51
	Combination	11.63
	Sulphur	10.95
Min Till	**Untreated**	9.51
	Standard	10.52
	Combination	10.57
	Sulphur	10.75
Plough	**Untreated**	8.95
	Standard	11.43
	Combination	11.92
	Sulphur	11.37

Conclusions

In this comparison, there was no clear difference in septoria severity on the flag leaf between the three different cultivation strategies, direct drill, min till and plough. There was also no significant difference in yield. The ploughed area did appear to senesce earlier than the other cultivation strategies but given that the cultivations were not randomised in the field, it is difficult to know whether this is a result of in field variation, or a true effect. It could suggest that as ploughing opens up the soil, releasing water, the ploughed area had reduced soil water content, causing it to senesce early. There were clear differences between the four fungicide strategies. The standard and combination programme performed similarly, both reducing septoria severity and increasing green leaf area compared to the untreated programme. When averaged across cultivation strategy both of these treatments significantly increased yields compared to the untreated, with the combined programme exceeding that of the standard. This therefore suggests that sulphur can replace folpet in a fungicide programme. The sulphur-based programme also performed well, reducing septoria and increasing green leaf area compared to the untreated, although not quite as effective as the standard or combined programme. Despite this, yield when averaged across cultivation strategy was similar to the standard. Therefore, sulphur-based fungicide products show great potential in replacing chemical fungicides in fungicide programmes where septoria is the dominant disease.

Methods

A field site was located near Stocksfield, England in a crop of winter wheat. Variation in vegetative growth across the field was examined using normalized difference vegetation index (NDVI) images. Prior to the comparison starting the field showed variation in NDVI, along an East to West line (Figure 3.1.11.3). The cultivation and fungicide treatment strategies were blocked across the field to encompass any differences in NDVI across tramlines (Figure 3.1.11.4).

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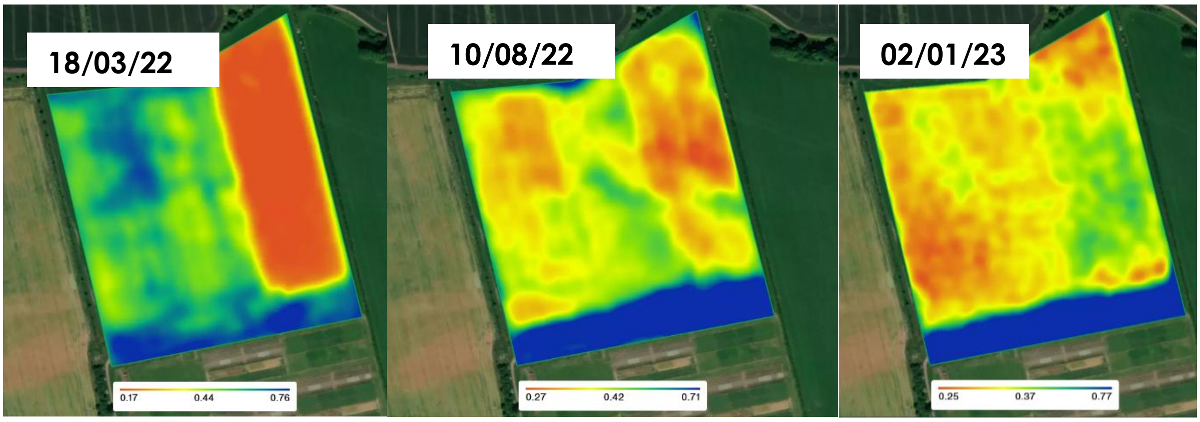

Figure 3.1.11.3: Normalized Difference Vegetation Index (NDVI) satellite images, obtained from www.datafarming.com.au, were utilized to depict the field's underlying variation. The NDVI scale ranged from 0 to 1, with colours shifting from red (low) through orange, yellow, and green to blue (high).

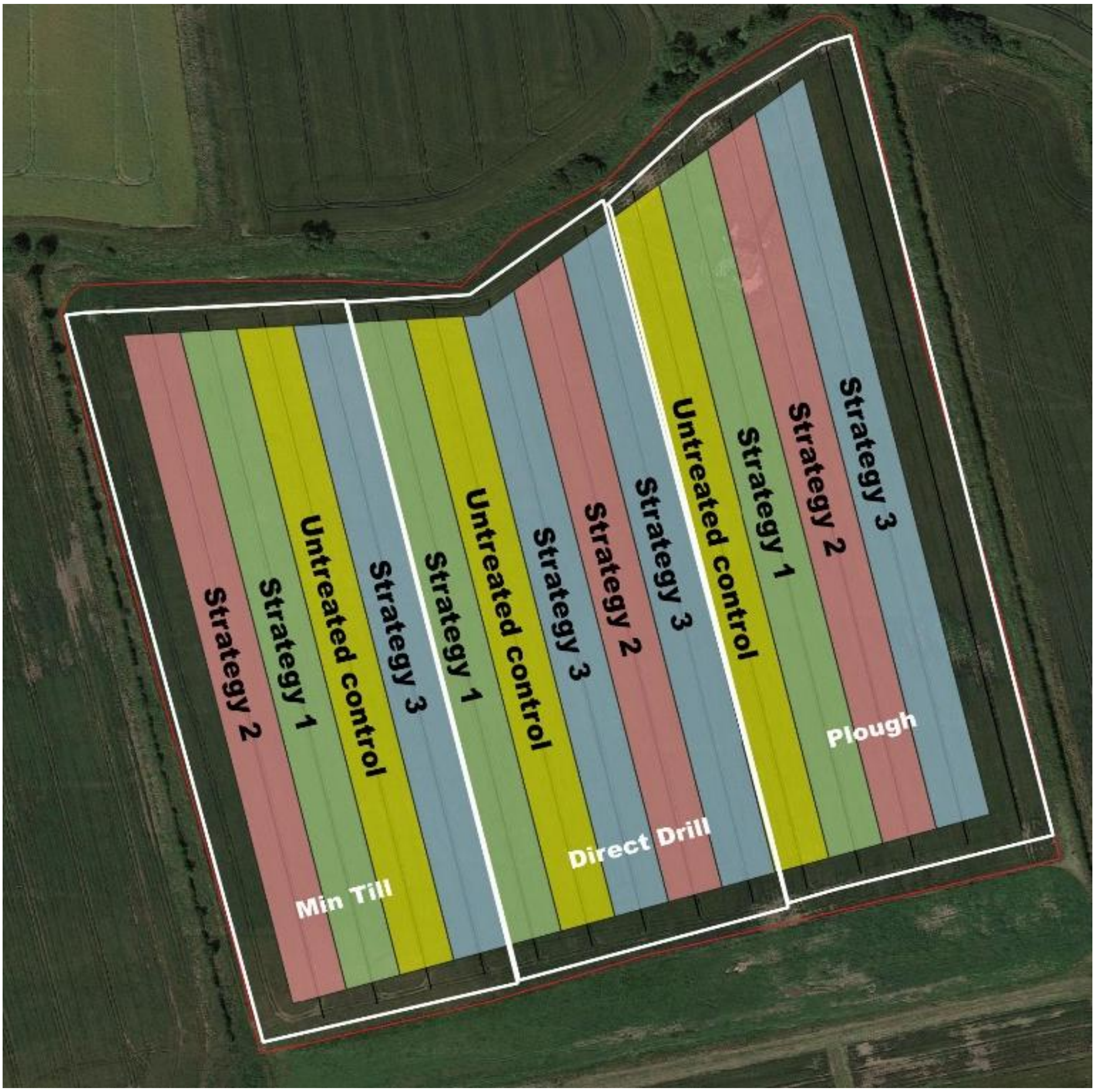

Figure 3.1.11.4: Layout of cultivation and fungicide strategies applied across the field of winter wheat.

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Strategies

The primary objective was to demonstrate the use of sulphur as an alternative to chemical fungicides under different cultivation practices. The comparison comprised of three cultivation strategies, each with three fungicide strategies and an untreated control (table 3.1.11.4). Strategy 1 followed the standard farm practice with the multi-site fungicide folpet included at T1 (GS32) and T2 (GS39). Strategy 2 replaced the folpet in strategy 1 with a sulphur based fungicide and was referred to here as the combination strategy. Strategy 3 utilised a sulphur-based fungicide. Sulphur has a low aqueous solubility and is not considered to be highly volatile. It may be persistent in soil but as a naturally occurring substance is unlikely to cause significant environmental problems. It is highly toxic to aquatic systems but tends to have a low toxicity to most other species. In this strategy, all fungicide application treatments, except that at T3 (GS65) were replaced with an application of sulphur. To determine the impact of disease prevalence there was also a strategy left untreated with fungicide within each cultivation.

Table 3.1.11.4: Cultivation and fungicide strategies carried out in this comparison.

Cultivation strategy	Fungicide strategy	Fungicide Treatments
Plough	**Standard**	T1 standard + folpet, T2 standard + folpet, T3 standard
	Combination	T1 standard + sulphur, T2 standard + sulphur, T3 standard
	Sulphur	T1 sulphur, T2 sulphur, T3 standard
	Untreated	No fungicide treatment
Min-till	**Standard**	T1 standard + folpet, T2 standard + folpet, T3 standard
	Combination	T1 standard + sulphur, T2 standard + sulphur, T3 standard
	Sulphur	T1 sulphur, T2 sulphur, T3 standard
	Untreated	No fungicide treatment
Direct drill	**Standard**	T1 standard + folpet, T2 standard + folpet, T3 standard
	Combination	T1 standard + sulphur, T2 standard + sulphur, T3 standard
	Sulphur	T1 sulphur, T2 sulphur, T3 standard
	Untreated	No fungicide treatment

Disease and yield assessments

An assessment of disease severity and green leaf area was made to quantify any differences in disease prevalence between the strategies. On the 26th July 2023, disease was assessed at 10 randomly spaced points within each strategy, at least 25m from the headland wheeling, spaced at least 10m apart, and at least 0.5m from the wheeling the assessor walked along. At each assessment point, the crop was parted, and the percentage leaf area infected with disease, and remaining green leaf area was estimated on the top two leaves (eventual leaf 1 and 2). Percentage cover for disease was estimated based on symptoms characteristically associated with infection. The field was harvested on the 23rd August 2023. The whole field was harvested with the same combine harvester on the same date.

Yield data analysis

Yield map data was analysed using an R Shiny graphical user interface (GUI) according to the detailed methods described by Marchant et al. (2019). Raw yield data were corrected to 15% moisture content and cleaned to eliminate systematic and random errors. These errors are identified by manual and automatic filtering, removing miscalculations in yield due to the combine running over areas that have already been harvested, changes in speed of harvest across the tramline, harvest rows where the swath width was less than a full header width etc. Rows of data points were straightened to refine the coarse geo-referencing quality provided by the harvester. Following this, a time shift was applied to account for the delay between the crop being cut and the grain yield being recorded by the monitor (Muhammed et al., 2014).

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The differences in yield between the strategies was investigated by applying a linear mixed model, accounting for spatial variation across rows and along rows. The modelled strategy effect with standard error of the difference (SED) provides the size of the strategy difference after excluding the effects of modelled underlying variation (Roques et al. 2022). Without access to the novel analysis software used in this here, comparisons between strategies could be conducted using a weighbridge. This would require calculating average yield per tramline, avoiding harvesting across the strategy boundary.

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3.1.12. IPMWORKS: Management of slugs in winter wheat in Spain

Authors: Aldaz Del Burgo, S.[1], Francis, C.[2] and Jones, I.[2]

1. INTIA, Spain
2. ADAS, England

Summary

Slugs are a common pest of arable and horticultural crops causing crop failure where slug pressure is high. Control is largely achieved through the use of chemical bait pellets; however, these are known to be harmful to vertebrates and there are concerns over the amount that is being found in water courses. In an effort to improve soil health and structure many growers have turned to reduced or no tillage, however this has resulted in multiple applications of chemical bait pellets where large amounts of crop residues provide a suitable environment for slug feeding and breeding, or unsuitable soil conditions result in direct drilling slots being poorly closed, making the seed vulnerable to slug predation. In this comparison in Spain in autumn 2023, a field was split in half, with one side being direct drilled and the other half cultivated, drilled and rolled to create a fine, consolidated seed bed to demonstrate the effect of tillage on slug populations. The INTIA warning station recommended an application of chemical bait pellets post drilling, so this was applied to the whole field to guard against yield loss. As a result, the number of slugs recorded in the refuge traps was low, however there were consistently fewer slugs where tillage had been completed. Highlighting the importance of integrating cultural control methods with chemical for control of slugs, in order to reduce the impact of chemical bait pellets on the environment.

Introduction

Slugs are a common pest in arable and horticultural crops, causing damage by feeding on seeds and seedings, destroying the growing point and reducing green leaf area, resulting in thin and patchy crops with a lower yield potential (Glen and Moens, 2002). Control of this damaging pest is often achieved through the use of chemical bait pellets which poison the slugs, however they are also poisonous to vertebrates (Homeida et al. 1982) and there are concerns about these chemicals being found in water courses (Keighley et al. 2021). It is therefore vital that slugs are managed using an integrated pest management approach to reduce the use of chemical bait pellets and its impact on the environment.

In an effort to improve soil health and structure many growers have moved to minimal, or no tillage systems to establish a crop. However, where this results in a lot of accumulated crop residues on the soil surface, such as where there are a lot of oilseed rape volunteers from the previous crop, or cover crop residues, this creates the optimal environment for slug feeding and breeding. Slugs can also be a bigger problem where direct drilling and seed slots are poorly closed (Davies and Finney, 2002). As such reduced or no tillage practices can lead to the requirement for multiple chemical bait applications (Cooper et al. 2020). The impact of slugs can be reduced by creating a fine, consolidated seed bed, or where seedbeds are cloddy, drilling seed a bit deeper (Glen 2000).

The use of chemical bait pellets can also be optimised to ensure they are only applied when absolutely necessary, where efficacy will be maximised. For example, pest thresholds can be used to indicate which crops are at risk of economic damage from slugs and require treatment and which crops have low slug populations unlikely to cause significant damage and therefore do not require control (Ramsden et al. 2017). As well as reducing crop damage from slug populations, this approach will also have economic benefits and it avoids the use of chemical bait pellets where not required, saving the grower the cost of the pellets, but also the labour and machinery costs of the application.

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Considering the risk of slugs in a crop, incorporating tillage strategies and targeted chemical bait pellet applications in an integrated approach to slug management will enable growers to achieve sufficient control of this challenging pest, while optimising margins and reducing impact on the environment. In this comparison in Spain, half of the field was direct drilled and the other half was cultivated, drilled and rolled to create a fine, consolidated seed bed to demonstrate the effect of tillage on slug populations. The whole field received a chemical bait pellet application of metaldehyde after drilling as instructed by the INTIA warning station[5], a tool for monitoring different pests and diseases fed with data from trap monitoring and field observations.

Results

Four slug refuge traps were set up in each strategy to monitor the level of slugs present. As metaldehyde was applied at the end of October, slug levels remained low throughout the monitoring period (table 3.1.12.1). However, with the exception of the 31st January, consistently more slugs were found in the traps located within the no tillage area each week, with up to 3 slugs per trap being found, whereas a maximum of 1 slug per trap was reported where tillage was completed. In total across the whole monitoring period, 20 slugs were seen in the no tillage traps compared to only 5 where tillage was completed. This data therefore supports the wider literature, which suggests tillage can be used to reduce slug pressure on crops.

Table 3.1.12.1: Number of slugs counted in each of the four traps weekly from the 24th October 2023 until 31st January 2024. Trap containing slugs have been highlighted in brown.

	Trap	24th October	10th November	22nd November	28th November	12th December	18th December	16th January	23rd January	31st January
No Tillage	1	0	3	0	0	0	0	2	1	1
	2	2	0	0	0	0	0	0	1	0
	3	3	0	0	0	0	0	2	3	0
	4	0	0	1	0	0	0	1	0	0
Tillage	1	0	0	0	0	0	0	1	0	1
	2	0	0	0	0	0	0	0	0	1
	3	0	0	0	0	0	0	0	0	0
	4	0	1	0	0	0	0	1	0	0

Conclusion

Slugs pose a threat to arable and horticultural crops by feeding on seeds and seedlings, taking out the growing point. This results in thin, patchy crops that in severe cases have to be redrilled to produce an economically viable crop. This comparison supports the wider literature in finding greater risk of slugs where no tillage is carried out. Direct drilling should be avoided where there are large amounts of crop residues on the soil surface or ground conditions are likely to result in poorly closed slots. In these circumstances growers should aim to produce fine, consolidated seedbeds to reduce the risk of slug damage. It may be necessary to utilise chemical bait pellets where pest pressure is high, but their use should be guided by thresholds or local decision support systems to ensure they are only applied where absolutely necessary. Utilising cultural controls such as tillage and seed depth, alongside considered application of chemical bait pellets where required, in an integrated approach to slug management, will avoid the unnecessary, overuse of chemical bait pellets, reducing the impact of slug management on the environment.

[5] https://estacionavisos.agrointegra.intiasa.es/ai/portalInicio.do?basedatos=bdAgrointegra

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Methods

Strategies

This comparison was designed to investigate the effect of tillage on slug populations (Table 3.1.12.2).

Table 3.1.12.2: Two strategies demonstrated in this comparison to evaluate the impact of tillage on slug populations

Strategy 1:	No Tillage
Strategy 2:	Tillage

Design

The chosen field was split in half, so that half of the field was direct drilled (No Tillage) and half of the field was cultivated before drilling (Tillage) (figure 3.1.12.1). The field was drilled on the 30th October and Metaldehyde slug pellets were applied after drilling as instructed by the INTIA warning station, a tool for monitoring different pests and diseases fed with data from trap monitoring and field observations.

Figure 3.1.12.1: 'In-field' comparison layout with the no tillage area in brown and tillage area in green.

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Slug Monitoring

Slug numbers were monitored in the field by setting up 4 refuge traps per strategy, of size 0.5 m x 0.5 m, giving a total area of 1 m^2. Traps were placed at least 10 metres apart and at least 10 metres away from the line which divides the two strategies. Traps were placed out in the evening after artificially wetting the traps to saturation, once the assessment had been made traps were moved a few metres and re-wetted.

Figure 3.1.12.2: Image of the slug trap used.

For each trap, two heaped spoonful's of bait was placed on the ground (bait should be non-toxic, such as chicken layers' mash or cereal grain-based food). Molluscicide baits must not be placed under the traps. A cover is added leaving a small gap between the cover and the soil to allow slugs to enter. Weighting the corner secures it in windy conditions.

Traps were checked weekly by lifting the cover, recording the actual date and growth stage of the crop. Counting and recording the number of slugs present in each trap.

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3.2. Vineyard

3.2.1. IPMWORKS: Using pheromone disruption to reduce grapevine moth damage in vineyards in Spain

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2. ADAS, England

Summary

The vine moth is a serious pest of grapevine in central and southern Europe. Larvae can destroy flower buds as well as cause death of open flowers and young fruitlets. They also destroy developing or maturing grapes. As a secondary consequence of the damage caused, fungal pathogens often invade, leading to further losses. Standard control strategies involve the use of chemical pesticides. To improve the timing and therefore success of applications, treatments can be applied during susceptible stages of the crop's development, when vine moth monitoring shows a peak in the population. Two to three applications may be applied to maintain control of this pest. In this comparison, in Spain in 2021, a standard fungicide strategy was carried out in one area and compared to the use of pheromones, placed within another area of the vineyard. The pheromones disrupt the ability of males to locate and reproduce with females, reducing moth populations. Both crops were monitored for damage and scored based on the percentage of grapes affected. Both strategies proved to be effective with very low levels of damage seen. The use of pheromones, however, meant that no chemical insecticides were applied, whereas two applications were required in the standard approach.

Introduction

The vine moth (*Lobesia botrana*) stands as a formidable pest of grapevines, particularly in central and southern Europe. This insect's larvae pose a substantial threat to grape crops by damaging flower buds, causing the death of open flowers and young fruitlets, and ultimately destroying developing or maturing grapes. The economic consequences of vine moth infestations extend beyond direct feeding damage, as secondary infections by fungal pathogens often compound losses (Milonas *et al.*, 2018). In the pursuit of effective pest management, the comparison between traditional chemical pesticides and the innovative use of pheromones has garnered significant attention.

Historically, chemical pesticides have been the cornerstone of moth control strategies, with applications timed to coincide with vulnerable stages in the grapevine's development. However, concerns surrounding the environmental impact of these chemicals, as well as the development of resistance in pest populations, have prompted a quest for more sustainable alternatives. Pheromones, chemical compounds emitted by female moths to attract mates, have emerged as a promising tool for disrupting the mating process and controlling vine moth populations. The environmental impact of chemical pesticides has raised concerns about the contamination of soil, water, and the harm inflicted on non-target organisms. Pheromones, being species-specific, reduce the risk of environmental contamination and collateral damage to beneficial insects, fostering a more sustainable and eco-friendly pest control approach (Cardé & Minks, 1995).

The specificity of pheromone-based control methods is a notable advantage over traditional chemical pesticides. Pheromone-based control methods are less prone to resistance development compared to chemical pesticides. By disrupting mating behaviours rather than directly affecting physiological processes, the likelihood of pests developing resistance is reduced, contributing to long-term effectiveness (Cardé & Minks, 1995). While chemical treatments may impact a broad spectrum of insects, pheromones target the

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vine moth's mating behaviour with precision, minimizing adverse effects on non-target species and ecosystems (Witzgall *et al*., 2010). Implementing pheromone-based pest control methods can have economic and environmental advantages by reducing the reliance on chemical pesticides and minimizing their negative impacts (Stelinski & Miller, 2008).

Comparative studies, such as the work conducted by Knight *et al*. (2016), have not only demonstrated the efficacy of pheromones in moth control, by revealing significant reductions in pest populations but also revealed a reduction of up to 10% in overall pesticide use. This reduction represents a meaningful step toward sustainable agricultural practices and aligns with the growing global emphasis on minimizing the ecological footprint of crop protection strategies. El-Sayed et al. (2006) investigated the effects of pheromone blends on lure efficacy for tortricid species (moths) in New Zealand. This research provides essential data on the optimization of pheromone-based strategies, emphasizing their adaptability and effectiveness across diverse pest species.

This comparison, carried out in Spain in 2021, aimed to illustrate diverse strategies for vine moth control in vineyards, evaluating their effectiveness and cost implications. Two areas were selected from the same region, implementing different strategies:

1. Chemical control aided by moth traps, employing strategically placed traps in vineyards, with advisors monitoring and signalling when to apply chemical insecticides.
2. Use of Pheromones, where synthetic pheromones induce sexual confusion, reducing moth populations.

Results

Chemical control aided by moth traps

Moths were collected in moth traps and recorded once a week. During the initial moth generation, marked by the initial peak on the graph (figure 3.2.1.1), no treatment was applied in the vineyard since there are no grapes susceptible to damage at that stage. Treatment is specifically initiated during the second generation, denoted by the second peak, and if there is an early appearance of the third generation; otherwise, treatment is omitted. In this case, chemical treatment was exclusively executed during the second generation, involving two separate applications spaced 14 days apart due to the prolonged duration of the infestation curve, persisting for nearly five weeks (Table 3.2.1.1). No treatment was administered during the third generation as it coincided with the proximity of the harvest season. The treatments demonstrated high efficacy, resulting in only 5% of the grapes being impacted (figure 3.2.1.2).

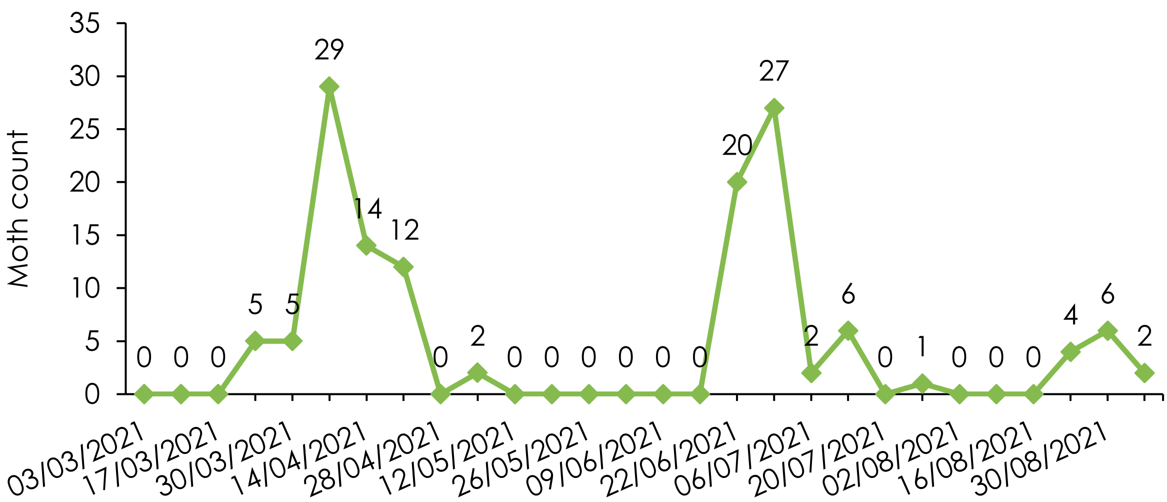

***Figure 3.2.1.1**: Moth numbers collected in traps every week to establish the life cycle of the moth and to apply treatments accordingly.*

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Table 3.2.1.1: Application dates and products used for managing vine moth infestations in 2021.

Application number	Application dates	Product name	Dosage	Efficacy Evaluation
1	24/06/2021	SINDOXA	0.125KG/HA	Good
2				

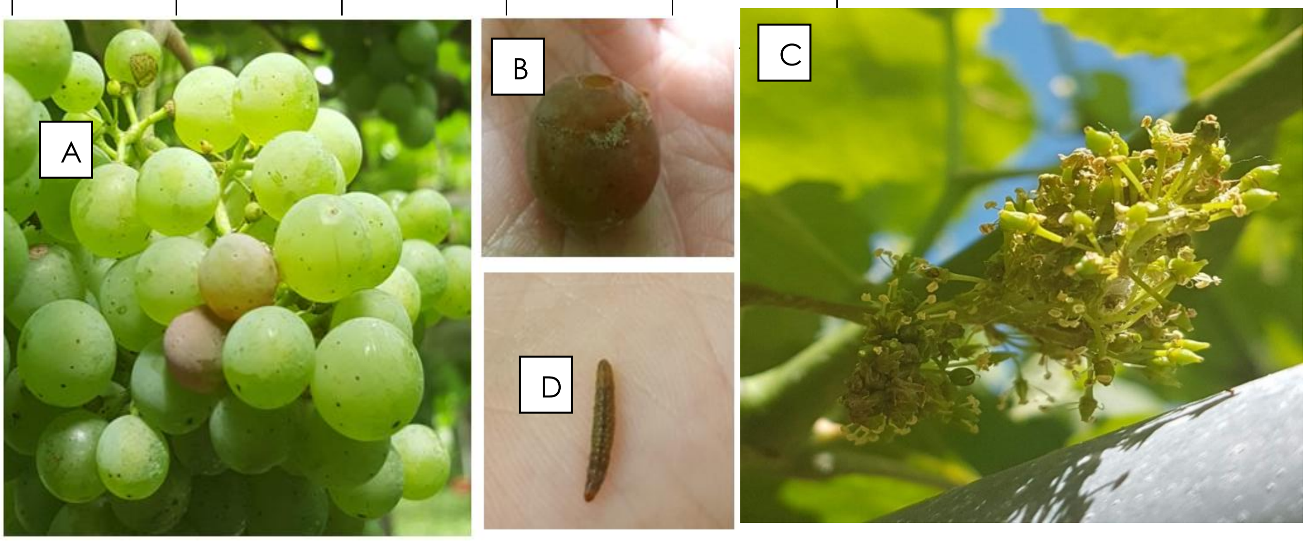

Figure 3.2.1.2. Photographs of damaged grapes and plant tissue (A-C) and vine moth larvae (D).

Use of Pheromones, where synthetic pheromones induce sexual confusion, reducing moth populations.

No chemical insecticides were utilised in this approach. Instead, pheromones known as Isonet L TT were employed in these vineyard plots. These pheromones are strategically positioned at a rate of 200 to 300 diffusers per hectare, which are affixed to the vineyard wires. These are installed at the outset of the growing season, typically in late March to early April, and they remain effective throughout the entire season, up to the conclusion of the grape harvest. The different types of diffusers employed in vineyards are illustrated in figure 3.2.1.3. The diffusers are removed at the end of the season or when replaced for the following year's cycle. The crop was monitored and less than 2% of grapes showed signs of crop damage.

Figure 3.2.1.3. Photographs of affixed diffusers of pheromones for male sexual confusion in vineyards in Spain.

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Economic analysis

Cost analysis of the two strategies, revealed that each chemical treatment incurred an approximate expense of €40 per hectare for the products used in 2021. In this example two applications were applied, totalling €80 per hectare. In addition to this is the cost of a tractor, sprayer and a tractor operator. In comparison, the approximate cost of the diffusers amounted to €115 per hectare, and their application was undertaken directly by the farmers themselves, requiring no more than an hour per hectare of labour, presenting a cost-effective solution to vine moth control.

Conclusions

In the battle against the vine moth, this 'in-field' comparison evaluated two control strategies, comparing chemical applications guided by moth traps and employing pheromones. Both strategies proved effective in minimizing damage, with only 5% of grapes affected in treated areas. Notably, the use of pheromones avoided the use of chemical pesticides compared to the traditional chemical approach, aligning with the global shift toward sustainable agricultural practices. Isonet L TT pheromones, strategically positioned in vineyards, resulted in less than 2% of grapes being affected. The cost-effectiveness and ease of application further enhance the appeal of pheromone-based control methods, showcasing their potential as a sustainable alternative. This comparison not only highlights the effectiveness of pheromones in vine moth control but also emphasizes the broader benefits; reduced environmental impact, decreased reliance on chemical pesticides, and a positive economic outlook. As agriculture strives for sustainability, the integration of innovative and targeted approaches, such as pheromone-based strategies, emerges as a promising path forward in pest management.

Methods

This 'in-field' comparison was designed to compare two strategies for control of vine moths in vineyards and compare their efficacy and cost. Two areas in the same region were selected as illustrated in figure 3.2.1.4, in which one strategy was carried out in each.

Strategy 1:	**Chemical control aided by moth traps:** Moth traps placed out in vineyards and monitored by advisors who alert growers when to apply a chemical insecticide
Strategy 2:	**Use of Pheromones:** Pheromones placed in the vineyards causing sexual confusion, reducing moth populations

Table 3.2.1.2: Table describing each strategy included in this demonstration

Figure 3.2.1.4: Image A shows the area where vine moths were controlled by chemical applications guided by moth trapping. Image B show the area where vine moths were controlled by pheromone traps.

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The following data for each area was collected:

- Which strategy they are using in each area
- Product names, rates and cost of any chemical insecticides or pheromones they applied as well as the dates of applications
- Where possible, recorded numbers of moths in the area collected in moth traps every week
- Assessment of crop damage (see below)
- Take photographs of any damage

Crop damage assessments

The severity of crop damage caused by codling moths was scored on a 1 to 5 scale by walking through each area checking for any damage, giving one score per area based on the average damage level. This assessment was completed at a time in the season when damage was likely to be seen.

1. No damage
2. Small amount of damage (< 25% grapes affected)
3. Moderate amount of damage (25-50% grapes affected)
4. High amount of damage (50-75% grapes affected)
5. Crop failure due to codling moths (100% grapes affected)

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3.2.2. IPMWORKS: Using cover crops to minimise herbicide use in vineyards in Greece

Authors: Kounani, K.[1], Francis, C.[2] and Jones, I.[2]

1. Agricultural University of Athens, Greece
2. ADAS, England

Summary

The integration of cover crops acts as a sustainable alternative to minimise herbicide reliance while enhancing soil health and biodiversity. This comparison explores the efficacy of this weed control approach within a vineyard setting in southern Greece in 2023, with a specific focus on the utilisation of common vetch, barley, and wild mustard cover crops. The comparison involved these cover crops and alternative weed management techniques, including mowing, pelargonic acid application, hot foam treatment, and an untreated control. Strips measuring 35 meters in length and 2.9 meters in width were established. Throughout the growing season, total cover crop and weed biomass was assessed within each strip, providing an indication of the weed control efficacy associated with each strategy. The aim was to demonstrate the potential of cover crops and alternative weed control methods in mitigating weed pressure while promoting sustainable vineyard management practices. The most effective weed control strategies in this comparison were the use of cover crops to out compete weeds or hot foam to control the weeds. Mustard tended to be the most effective monocrop, however the combination of barley, vetch, and mustard cover crops resulted in higher biomass production and therefore better weed control than using a solo species, highlighting the effectiveness of diversified cover crop mixtures.

Introduction

Viticulture, the cultivation of grapevines, plays a pivotal role in the global wine industry. As vineyard management practices evolve, there is a growing recognition of the environmental impact of conventional weed control methods, such as herbicides, on both the ecosystem and grape quality. In response to these concerns, the adoption of cover crops in vineyards has gained momentum as a sustainable alternative with numerous benefits. Cover crops contribute to enhanced soil structure and fertility. They act as green manure, adding organic matter to the soil, promoting microbial activity, and preventing erosion. This is crucial for maintaining optimal soil health in vineyards, as healthy soils are directly linked to grapevine vitality and grape quality (Smith et al., 2017). One of the primary advantages of cover crops is their ability to suppress weed growth naturally. By outcompeting weeds for sunlight, water, and nutrients, cover crops reduce the need for synthetic herbicides, minimizing the environmental impact and potential residues in the final wine product (Wilson et al., 2020). According to a recent study by Fleishman et al. (2023), cover crops growing under grapevines reduced vegetative growth between 13% and 30% across all five years of the study, with substantial reductions in the first two years. Grape yields were reduced in only three out of five years, ranging from 9% to 25%, depending on the rootstock. Cover crops also create a diverse ecosystem within the vineyard, fostering the presence of beneficial insects and microorganisms. This biodiversity helps control pests and diseases, reducing the reliance on chemical interventions. Moreover, the ecological balance provided by cover crops can positively influence the overall vineyard ecosystem (Johnson and Luna, 2019).

Unlike chemical herbicides, cover crops offer an environmentally friendly solution to weed control. The absence of harmful residues in the soil and waterways minimizes negative impacts on non-target organisms, ensuring a more sustainable approach to vineyard management (Gladwin et al., 2018). While initial investment and management of cover crops may incur some costs, in the long term, they often prove more

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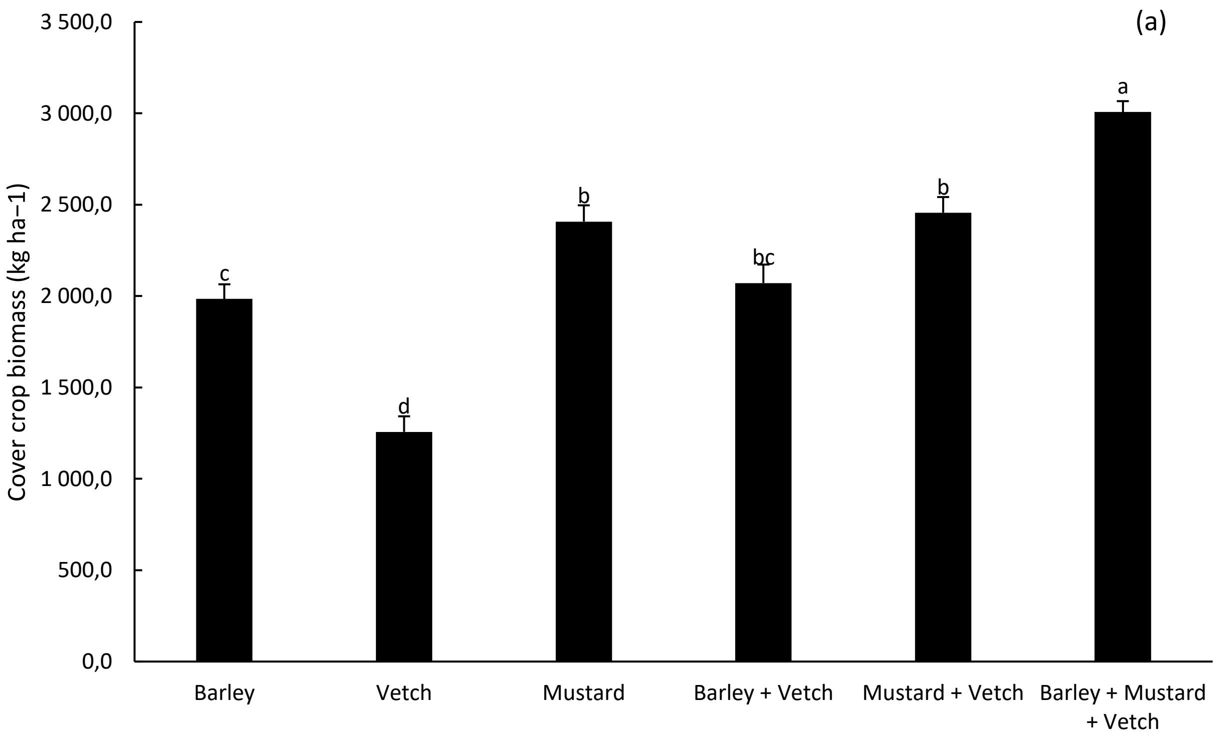
cost-effective than repeated applications of herbicides. Cover crops contribute to reduced erosion, water runoff, and soil degradation, which can translate into long-term economic benefits for vineyard operators (Reganold et al., 2015). The positive effects of cover crops on soil health and grapevine vitality are reflected in the quality of the final wine product. Studies suggest that vineyards employing cover crops exhibit improved grape characteristics, including enhanced aroma profiles and a more balanced grape composition (Hogarth et al., 2021).

The comparison carried out in the region of Corinthia, Greece in 2023 demonstrated the effectiveness of alternative weed control strategies in vineyards, focusing on common vetch, barley, and wild mustard cover crops and comparing them to weed management techniques such as mowing, pelargonic acid application, hot foam treatment, and an untreated control. Strips measuring 35 meters by 2.9 meters were established, and the cover crop and weed biomass assessed. The aim being to demonstrate the potential of cover crops and alternative methods in reducing weed pressure while promoting sustainable vineyard management practices.

Results

Cover crop biomass

Growing three cover crop types together resulted in the highest biomass production at both assessment timings. In the first assessment, 45 days after sowing (45 DAS), the mustard monoculture and the mixture of mustard and vetch also showed high productivity (figure 3.2.2.1a). At the second assessment 90 days after sowing (90 DAS), while the mustard monoculture and mixtures of two cover crop types produced less biomass than the triple cover crop mixture, they still had higher biomass than the barley and vetch monocultures (figure 3.2.2.1b). Barley exhibited higher biomass production than vetch at 45 DAS, a trend similarly observed at 90 DAS.



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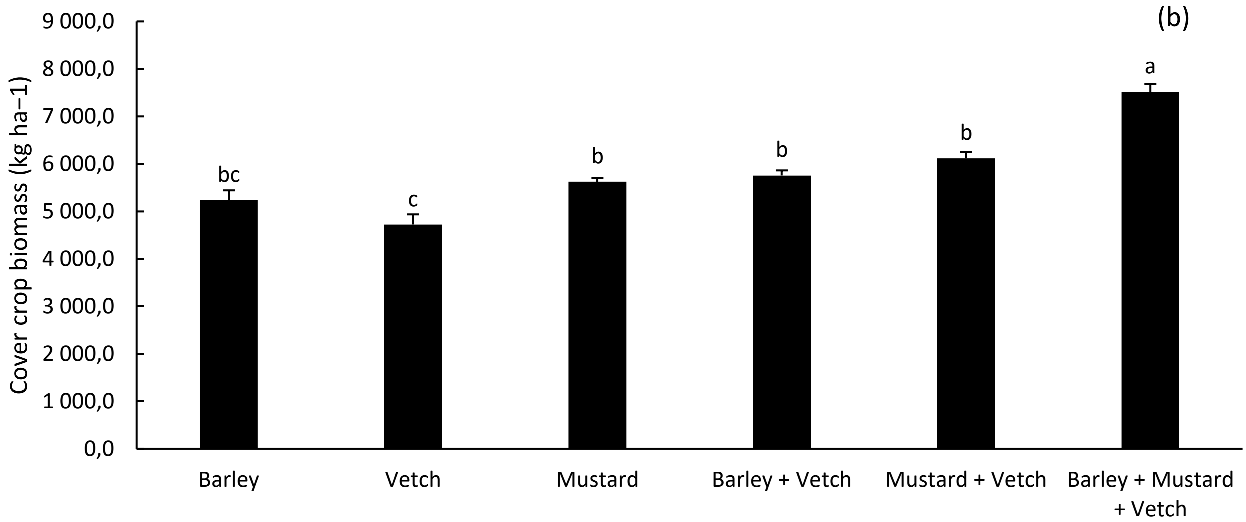
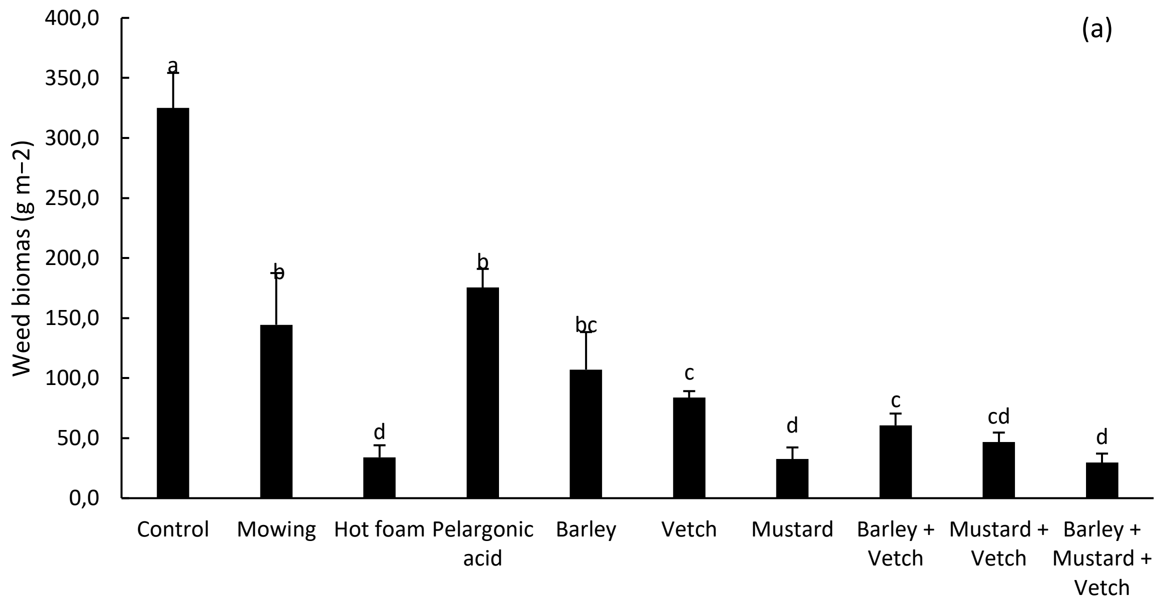


Figure 3.2.2.1: Cover crop biomass (kg ha^{-1}) in (a) the first assessment 45 days after sowing and (b) the second assessment 90 days after sowing. Different lowercase letters indicate significant differences (P<0.001). Vertical error bars indicate standard errors of measurements.

Winter weed biomass

At the first assessment (45 DAS), the combination of three cover crop types, mustard monoculture, and hot foam application resulted in the lowest winter weed biomass production (figure 3.2.2.2a). Mustard with vetch and barley with vetch mixtures, along with vetch and barley monocultures, exhibited notable weed-suppressing effects. Mowing and pelargonic acid treatments were least effective, but still achieved a significant reduction in weed biomass compared to the untreated control strips.

At the second assessment (90 DAS), the combination of three cover crop types and hot foam application resulted in the lowest winter weed biomass (figure 3.2.2.2b). Mustard monoculture and mustard with vetch mixtures also showed significant weed suppression, closely followed by barley with vetch, barley monoculture, and vetch monoculture. Mowing and pelargonic acid treatments were the least effective strategies, but still achieved a significant reduction in weed biomass compared to the untreated.



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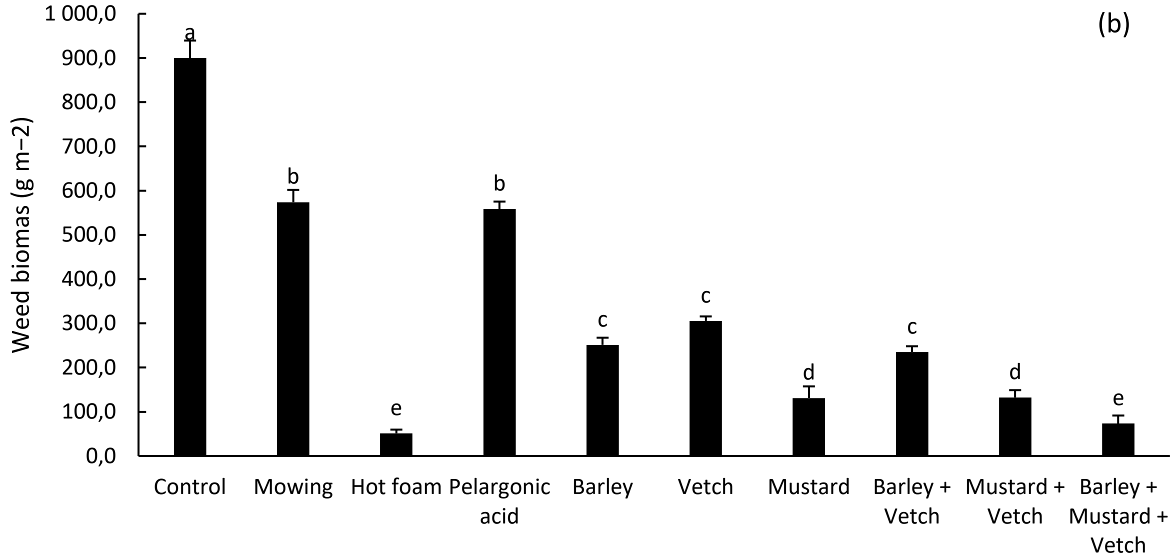
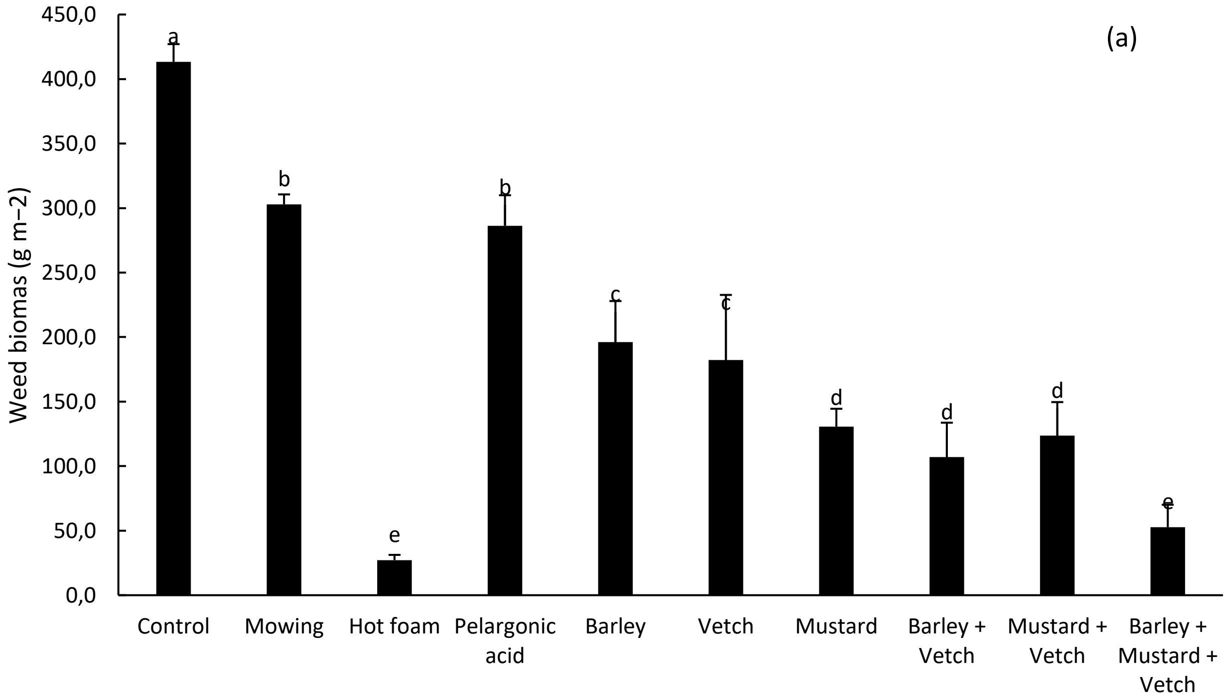


Figure 3.2.2.2: Winter weed biomass (g m^{-2}) in (a) the first assessment 45 days after sowing and (b) the second assessment 90 days after sowing. Different lowercase letters indicate significant differences (P<0.001). Vertical error bars indicate standard errors of measurements.

Summer weed biomass

The three species mix of barley, mustard and vetch and the hot foam treatment resulted in the lowest summer weed biomass at the first assessment 45 days after termination of the cover crops (45 DAT) (figure 3.2.2.3a). Mustard with vetch, barley with vetch, and the mustard monoculture also achieved good suppression of summer weed biomass, closely followed by barley and vetch monocultures. Mowing and pelargonic acid were the least effective weed control treatments, but both still achieved a significant reduction in weed biomass compared to the untreated control.



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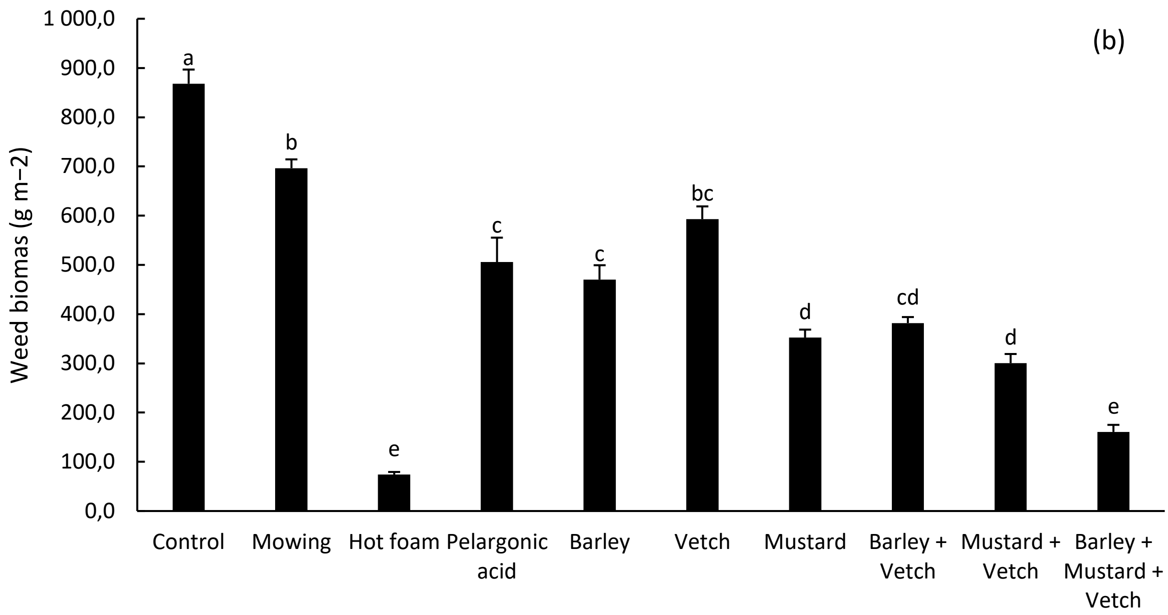

Figure 3.2.2.3: Summer weed biomass (g m^{-2}) in (a) the first assessment 45 days after termination of the cover crops and (b) the second assessment 90 days after termination of the cover crops. Different lowercase letters indicate significant differences (P<0.001). Vertical error bars indicate standard errors of measurements.

At the second assessment 90 days after cover crop termination (90 DAT), hot foam and the three species mix of barley with mustard and vetch resulted in the lowest biomass of summer weeds (figure 3.2.2.3b). The mustard monoculture, mustard with vetch mixture and barley with vetch also achieved significant weed suppression, closely followed by the barley monoculture, and vetch monoculture. Pelargonic acid efficacy was comparable to barley and vetch monocultures. Mowing was the least effective strategy but still achieved a reduction in summer weed biomass compared to the untreated control.

Correlations

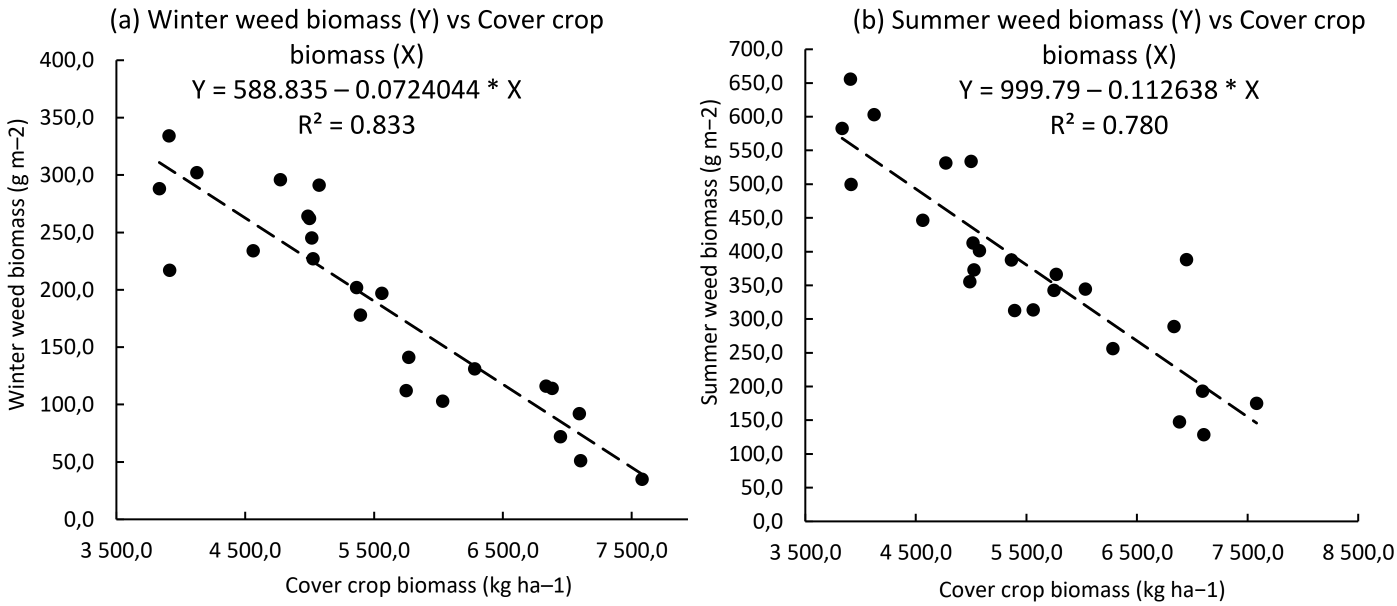

Figure 3.2.2.4: Regression analysis between (a) winter weed biomass (g m^{-2}) and cover crop biomass (kg ha^{-1}) and (b) summer weed biomass (g m^{-2}) and cover crop biomass (kg ha^{-1}). Winter/summer weed biomass is the depended variable (Y) and cover crop biomass the independent variable (X).

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Strong negative linear regression was observed between winter weed biomass and cover crop biomass (figure 3.2.2.4a). Similar trends were observed for summer weed biomass, showing a decrease as cover crop biomass increased (figure 3.2.2.4b). Both winter and summer weed biomass also decreased as the number of different species increased in cover crop treatments (Figure 3.2.2.5). Additionally, a strong positive polynomial relationship was found between cover crop biomass and cover crop species richness (figure 3.2.2.6). This demonstrates that increasing the number of species in a cover crop mixture increases the total cover crop biomass and therefore increases competitiveness of the mix against weeds. Improving the weed control achieved by a cover crop.

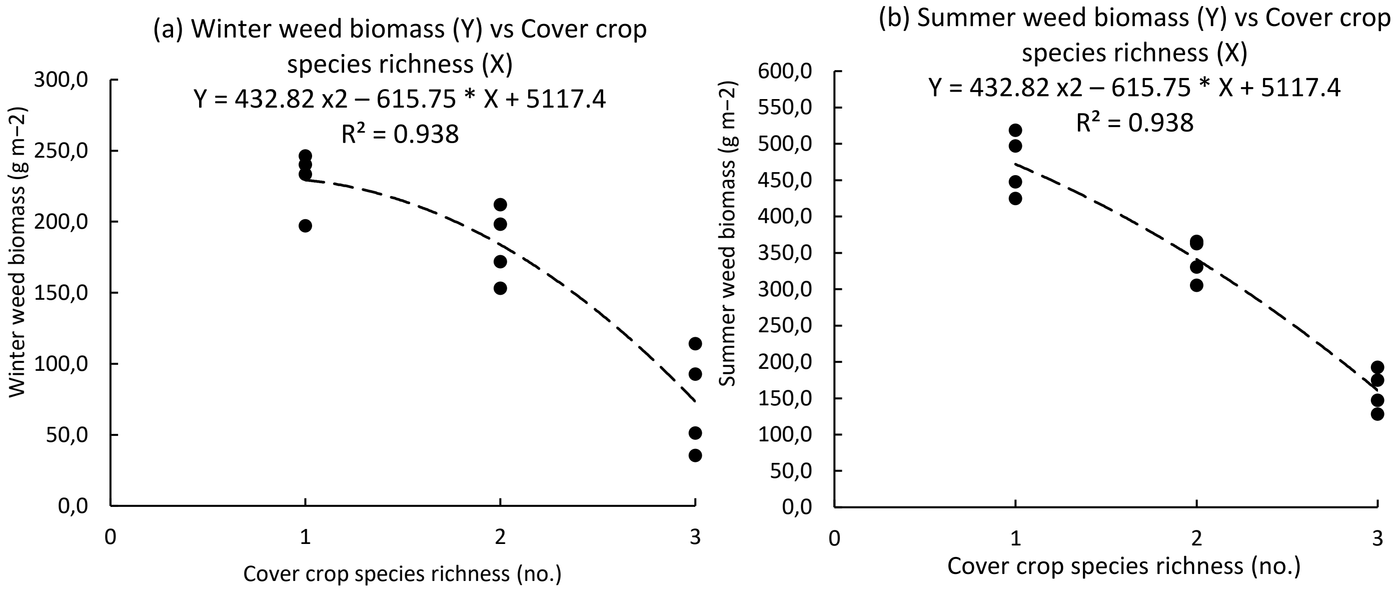

Figure 3.2.2.5: Polynomial relationship between (a) winter weed biomass (g m^{-2}) and (b) summer weed biomass (g m^{-2}) against cover crop species richness.

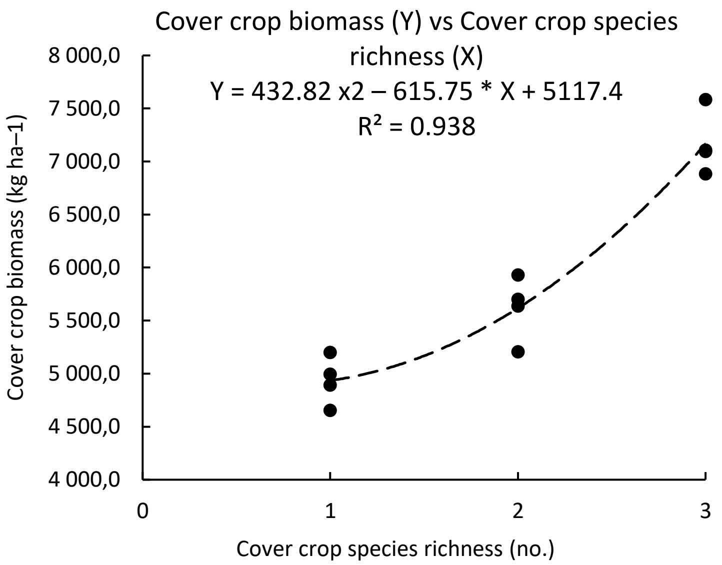

Figure 3.2.2.6: Polynomial relationship between cover crop biomass (kg ha^{-1}) and cover crop species richness (no.).

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Photographs

Figures 3.2.2.7 and 3.2.2.8 show images of each cover crop strategy taken on the 22nd April.

Figure 3.2.2.7: Images of the different monocrop cover crop strategies, a) untreated, b) barley, c) mustard and d) common vetch taken on the 22nd April 2023.

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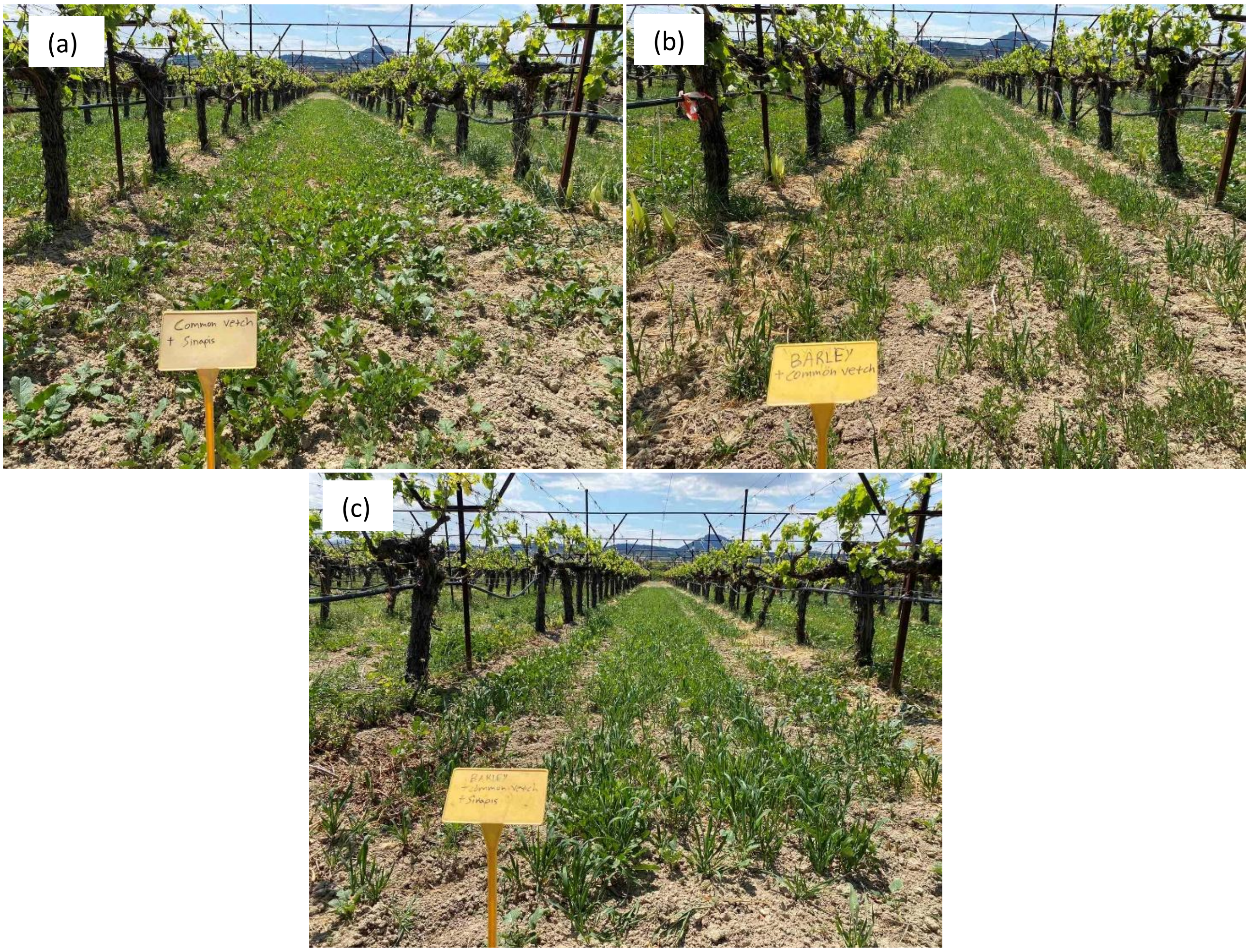

Figure 3.2.2.8: Images of the different multispecies cover crop strategies, a) Common vetch with mustard, b) barley with common vetch and c) barley with common vetch and mustard, taken on the 22nd April 2023.

Conclusions

The most effective weed control strategies in this comparison were the use of cover crops to out compete weeds or hot foam to control the weeds. Mustard tended to be the most effective monocrop, however the combination of barley, vetch, and mustard cover crops resulted in higher biomass production and therefore better weed control than using a solo species, highlighting the effectiveness of diversified cover crop mixtures. Notably, a robust negative linear regression highlighted the substantial impact of cover crop biomass on weed suppression, while a positive polynomial relationship emphasized the importance of cover crop diversity in reducing winter and summer weed biomass. This comparison has therefore demonstrated some very useful weed management techniques for use in vineyards, reducing the requirement for chemical herbicides, contributing to the development of sustainable practices in vineyards and other economically significant perennial crops.

Method

Comparison design

This comparison took place from March to September 2023 in a vineyard in Greece and entailed an evaluation of ten distinct weed management strategies. Each strategy was implemented in 35 m long, 2.9 m wide strips. Weed control strategies included an untreated control, mowing, cover crop monocultures and mixtures, pelargonic acid, and hot foam applications. The aim was to demonstrate alternative weed control strategies.

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Weed control strategies

Cover crops and other non-chemical weed control methods in the vineyard (*Vitis vinifera* L.)

Table 3.2.2.1: Weed control strategies demonstrated in this comparison.

	Weed control strategies
1	Common vetch (*Vicia sativa* L.) cover crop
2	Barley (*Hordeum vulgare* L.) cover crop
3	Wild mustard (*Sinapis arvensis* L.) cover crop
4	Barley + common vetch cover crop mixture
5	Wild mustard + common vetch cover crop mixture
6	Wild mustard + barley + common vetch mixture
7	Mowing
8	Pelargonic Acid
9	Foamstream (hot foam)
10	Untreated control

The selected cover crops, barley (*Hordeum vulgare* L.), vetch (*Vicia sativa* L.), and mustard (*Sinapis alba* L.), were scrutinized as monocultures and in various combinations, broadcast sown on the 15th March 2023. To prepare the seedbed, a rotary hoe plough was used at a 25 cm depth. Sowing was also timed to be before expected rainfall to promote seed germination. The seed rates of each cover crop species are listed in table 3.2.2.2. The cover crops were terminated by flail-mowing on the 16th June 2023 and their residues were left on the soil surface to suppress the emergence and growth of summer weeds.

Table 3.2.2.2: Seed rates for the different cover crop strategies.

	Seeding rates	
1	Common vetch	180 kg ha^{-1}
2	Barley	180 kg ha^{-1}
3	Wild mustard	15 kg ha^{-1}
4	Barley + Common vetch	100 kg ha^{-1} + 100 kg ha^{-1}
5	Wild mustard + Common vetch	8 kg ha^{-1} + 100 kg ha^{-1}
6	Barley + Wild mustard + Common vetch	55 kg ha^{-1} + 5 kg ha^{-1} + 55 kg ha^{-1}

Non cover crop strategies were flail-mown on the 15th March 2023 to clear the area of large winter weeds because both pelargonic acid and hot foam are bioherbicides with no systemic activity and should, therefore, be applied at early weed growth stages. Pelargonic acid was applied twice at a rate of 1,088 g a.i. ha−1 at a two-week interval on the 22nd April and 4th May 2023 to control winter weeds, and then again on the 14th July and 29th July to control summer weeds. Applications were done with a pressurized Gloria® 405 T sprayer calibrated to deliver 300 L ha−1 of spray solution at constant pressure of 200 kPa through five flat-fan nozzles. At the time of the first application, weed flora consisted of winter weed species and weeds had four to eight true leaves (BBCH: 14–18).

Mowing treatment was applied with a flail-mower on the 6th May 2023 and repeated on the 31st July 2023.

Hot foam was applied on the 4th May 2023 and 30th July 2023, using the novel Foamstream® M1200 machine (Weedingtech Ltd., London, UK). The machine was placed on a trailer and towed on the field. The solution used was a 100% mixture of plant oils and sugars i.e., alkyl polyglucoside surfactants. The foam was manually applied using a 0.3 m wide hot foam spreader at a rate of 13.33 L m−2. The flow rate was 12 L min−1 or 0.2 L s–1 (96% water and 4% Foamstream V4). Weeds were between the 18 and 22 BBCH growth stages at the time of the first application.

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Cover crop and weed biomass assessments

To assess treatment efficacy on winter weeds, cover crop and weed biomass were harvested from four $1m^2$ areas marked with a wooden quadrat placed randomly in each strip at 45 and 90 days after cover crop sowing (45 and 90 DAS). To assess treatment efficacy on summer weeds, cover crop and weed biomass were harvested from four random $1m^2$ areas in each strip at 45 and 90 days after cover crop termination (45 and 90 DAT). Samples were oven-dried (65 °C for 48 h) to measure cover crop and weed biomass using a digital balance.

All data were subjected to one-way ANOVA and means were compared using Fischer's Least Significant Difference (LSD) test. Weed and cover crop biomass were correlated according to the linear model

$$Y = A + B * X$$

where weed biomass (winter/summer) was the dependent variable (Y) and cover crop biomass was the independent variable (X). Cover crop and weed biomass (winter/summer) were correlated with cover crop species richness according to the second degree polynomial $Y = C + A * X + B * X^2$ where cover crop or weed biomass (winter/summer) was the dependent variable and cover crop richness was the independent variable.

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3.2.3. IPMWORKS: Using holistic approaches to manage green leafhopper in vineyards in Portugal

Authors: Cardoso, B.[1], Castro, B.[1], Francis, C.[2] and Jones, I.[2]

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2. ADAS, England

Summary

The green leafhoppers migrate to vineyards in the spring, where they complete 3 to 5 generations per year. Adults lay eggs inside the epidermis of the leaves, from which nymphs emerge. The nymphs bite into the veins of the plants, feeding on the sap. Their saliva is toxic, causing the vessels to become blocked, preventing circulation of sap and as a result the affected areas die. Symptoms can appear 3 to 4 weeks after nymphs appear, reddening or yellowing of the margin of the leaves is seen, which progresses to leaf death and premature defoliation of the vines. Control of this pest is achieved by monitoring the number of nymphs in the crop and then applying insecticides once a threshold of 50 nymphs per 100 leaves is reached. In this comparison, carried out in Portugal in 2023, the application of insecticide to a whole area once the threshold is reached, was to be compared to an area where only the edges of the area received insecticide. However, this season the threshold was not reached and so no insecticide was applied in either strategy. This shows the benefit of monitoring pests and having a set threshold in ensuring insecticide applications are only applied where necessary.

Introduction

Vineyards play a crucial role in the global wine industry, representing a significant economic and cultural asset. However, the cultivation of grapevines is often challenged by various pests, among which the green leafhopper (*Empoasca spp*.) stands out as a notorious threat. The green leafhopper, poses a substantial risk to vineyard health by feeding on the plant, releasing their toxic saliva into the leaves interrupting the circulation of sap causing necrosis and leaf death (Infovini 2024). In the pursuit of effective pest management strategies, the application of insecticides has been a common approach. In modern agriculture, the use of insecticides is crucial for pest management, but the indiscriminate application of these chemicals can have detrimental effects on the environment, non-target organisms, and human health. The use of pest thresholds as part of an integrated pest management strategy has emerged as a sustainable approach that advocates for the targeted and sensible use of insecticides.

Precision insecticide application minimizes the overall environmental impact by reducing the amount of chemicals released into the ecosystem. This is crucial for maintaining biodiversity and ecological balance (Smith *et al*., 2019). Broad-spectrum insecticides can harm beneficial insects and other non-target organisms, leading to disruptions in natural pest control mechanisms. Targeted insecticide application allows for the preservation of beneficial insects, promoting a more sustainable agroecosystem (Goulson *et al*., 2015). By specifically targeting areas with nymph infestations, farmers can optimize insecticide use, applying chemicals only where they are needed. This targeted approach minimizes the overall environmental impact and helps conserve natural predator populations (Liang *et al*., 2017). Using fewer insecticides also helps mitigate the issue of pesticide residues in crops, soil, and water. Residue accumulation can have adverse effects on human health and contribute to the development of pesticide-resistant pest populations (Furlong *et al*., 2018). Monitoring nymphs on leaves provides an early detection mechanism for pest infestations. Early identification allows farmers to intervene promptly and effectively, reducing the need for extensive insecticide application (Damos and Savopoulou-Soultani, 2012), resulting in more cost-effective solutions (Osteen and Fernandez-Cornejo, 2013).

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By employing advanced technologies such as remote sensing and automated surveillance, researchers have demonstrated the ability to detect pest presence at early stages, enabling prompt and targeted interventions (Smith et al., 2019; Jones et al., 2021). Early detection not only curtails potential crop damage but also contributes to a more precise and judicious use of insecticides. Setting specific thresholds for insecticide application is a key component of integrated pest management (IPM) strategies. The establishment of these thresholds involves a comprehensive understanding of the interactions between pests, crops, and environmental factors. Research by Brown et al. (2020) highlights that applying insecticides only when pest populations surpass predetermined thresholds not only reduces the overall quantity of chemicals used but also mitigates the risk of developing pesticide-resistant pest strains. Moreover, adopting a threshold-based approach aligns with the principles of ecological sustainability. By preserving natural enemies of pests and promoting biological control, farmers can harness the ecosystem's intrinsic resilience, creating a more balanced and harmonious agricultural environment (Zhang et al., 2022; Johnson and Smith, 2018).

In this 'in-field' comparison carried out in Monte Branco, Portugal in 2023, the aim was to demonstrate the combined use of pest thresholds and targeted pesticide applications in a holistic approach to green leafhopper control. Two strategies were carried out within a vineyard to compare the outcomes of applying insecticide across an entire plot (strategy 1) against applying it exclusively along plot edges (strategy 2). By targeting the edges, where the pests are often more concentrated due to migration from adjacent crops or habitats, practitioners aim to intercept and control the population before it spreads throughout the entire vineyard. In both strategies, the number of nymphs in the crop were monitored and insecticides only applied once a threshold of 50 nymphs per 100 leaves is reached.

Results

The two strategies were monitored for green leafhopper nymphs weekly by counting the number of nymphs on a total of 100 leaves in each plot (figure 3.2.3.1). The number of nymphs in each strategy was very similar and the population slow to progress, only exceeding the threshold for insecticide treatment late in the season, by which time harvest was approaching, and it was too late to apply any pesticides as harvest intervals would be breeched. Therefore, neither strategy received an insecticide, so the use of a more targeted insecticide application around the edge of a plot compared to the whole plot could not be compared. This comparison does however demonstrate the benefits of using a pest threshold for insecticide use.

The vine leaves were also assessed weekly for green leafhopper damage on a scale from 0 (no damage) to 4 (complete necrosis) (table 3.2.3.1). The frequent scoring of 0 for the majority of monitored leaves in both strategies and the damage rating not reaching higher than 2 were consistent with the low number of nymphs, further validating the use of a pest threshold to ensure insecticides are only applied where pest infestations reach a level where crop losses are highly likely, and use of pesticides become economically justifiable. As shown here, thresholds can save growers money in lower pressure seasons where applications are not required.

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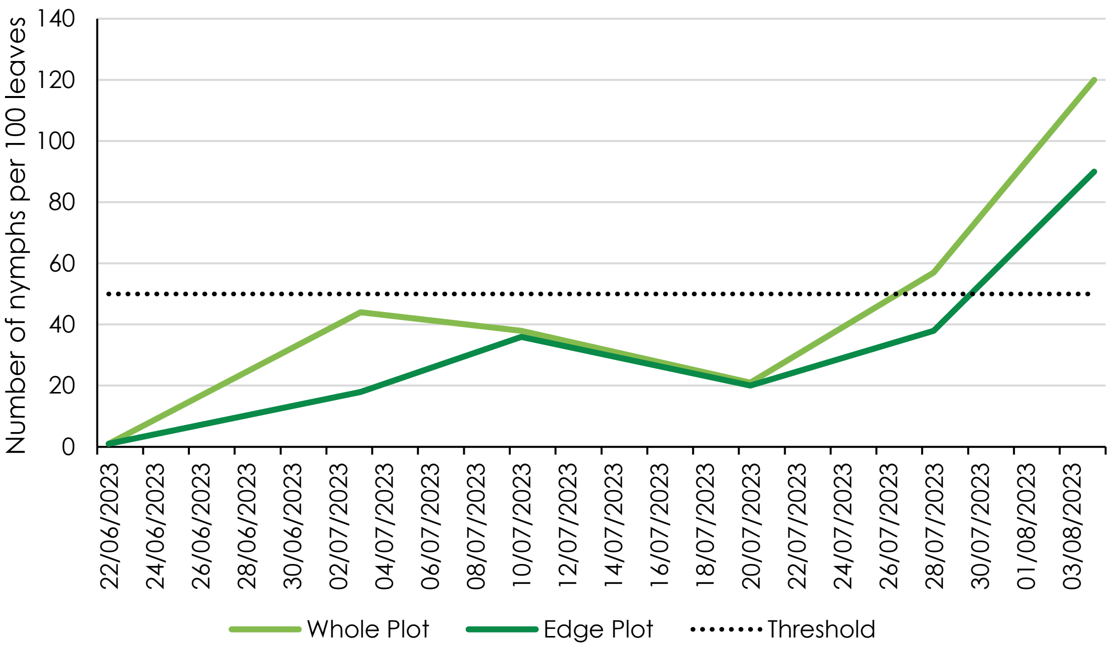

Figure 3.2.3.1: Weekly monitoring of nymphs in the whole plot (light green) and edge plot (dark green) from the 22nd June 2023 until the 4th August 2023. The dotted line represents the threshold for an insecticide application at 50 nymphs per 100 leaves.

Table 3.2.3.1: Leaf damage scored weekly from the 22nd June 2023 on a 0 to 4 scale. 0 = No damage symptoms, 1 = Slight damage, yellowing of leaves, 2 = Moderate damage, slight necrosis of the margins, 3 = Severe damage, advanced necrosis, 4 = Leaf is completely necrotic. Numbers represent the number of leaves scored as a 0, 1 or 2 on each assessment date. No leaves were rated 3 or 4.

	Damage Score	22/06/23	03/07/23	10/07/23	20/07/23	28/07/23	04/08/23
Whole Plot	0	78	70	83	57	41	37
	1	19	30	15	38	59	59
	2	3	0	2	5	0	4
Edge Plot	0	80	75	71	62	49	18
	1	17	25	27	37	47	76
	2	3	0	2	1	4	6

Conclusions

In this comparison, weekly green leafhopper nymph counts showed that population growth was slow and did not reach the threshold for control until very late in the season, therefore chemical control was not required. This was confirmed by leaf damage assessments where only minor symptoms were observed. Although this meant that the use of a targeted insecticide application around the edge of a plot could not be compared to a whole plot application, the value of pest thresholds for insecticide use was clear. Crops can often tolerate a level of pest infestation without significant crop damage and impact on yield. The development of carefully designed thresholds, based on comprehensive knowledge of a pest's life cycle and of potential crop losses, are essential to ensure that insecticides are only applied where absolutely necessary to maintain yield. The benefits of pest thresholds include cost savings where pest populations are below threshold and minimising insecticide usage, which reduces the impact of agriculture on non-target species, delays the development of pesticide resistance and reduces pesticide residues in food, drink and water courses, fostering a balance between economic considerations and environmental stewardship.

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Methods

Strategies

This comparison was designed to demonstrate the control of green leafhopper in vineyards, comparing pest damage where insecticide has been applied across a whole plot with a plot that has only had insecticide sprayed along the edges. The application of insecticides was determined by using a pest threshold of 50 nymphs per 100 leaves.

Table 3.2.3.2: The two strategies tested in this 'in-field' comparison to evaluate control of green leafhopper in vineyards.

Strategy 1:	Whole plot insecticide application once pest threshold reached
Strategy 2:	Only the edges of the plot receive insecticide once pest threshold reached

Design

Two different plots of a vineyard of similar size were selected (figure 3.2.3.2). Both were monitored for green leafhopper. Plant protection products were applied when this pest's Economic Attack Level (EAL) is reached. In one of the plots, the insecticide application should be carried out on the whole plot, and in the other plot, the insecticide application should only made on the borders. The EAL was 50 nymphs in 100 leaves[6].

Figure 3.2.3.2: Image showing the location of the two strategies in the vineyard.

[6] https://en.avipe.pt/copia-acaros-1

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Monitoring nymphs on leaves

- Weekly monitoring of nymph levels.
- 50 vines in each plot were randomly selected. In strategy two these vines were selected in the borders. The distribution of the monitored vines in each plot were similar and covered the entire plot monitored.
- On each vine, the 7th-8th leaf were selected.
- The number of nymphs on each leaf were counted and recorded.
- The presence of other important pests was also recorded.

Leaf damage assessment

- Weekly leaf damage assessments completed.
- 50 vines in each plot were randomly selected. In strategy two, these vines were selected in the borders. The distribution of the monitored vines in each plot were similar and covered the entire plot monitored.
- On each vine, two leaves were selected.
- Leaf damage was classified according to the following scale (0-4):
  0 - No symptoms are visible on the leaves.
  1 - Slight damage: yellowing of leaves.
  2 - Moderate damage: slight necrosis on the margins.
  3 - Severe damage: advanced necrosis.
  4 - The leaf is completely necrotic.

• The damage scores were recorded.

Level 2	Level 3

Figure 3.2.3.3: Example images showing a leaf classified as level 2 and level 3 damage score.

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3.3. Soft Fruits

3.3.1. IPMWORKS: Using biocontrol for soft fruit root diseases in Finland

Authors: Kallela, M.[1], Francis, C[2] and Jones, I.[2]

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Summary

The use of biological fungicides, fungicides that contain a microorganism as the active ingredient, can help to reduce reliance on chemical fungicides. An example is LALSTOP G46 WG, a biological fungicide used in the production of vegetables, fruits, herbs and ornamentals. LALSTOP G46 WG consists of mycelium and spores of a naturally occurring soil fungus, *Clonostachys rosea* strain J1446, that provides control of a range of crop diseases. The efficacy of LALSTOP G46 WG was demonstrated in Pirkanmaa, Finland in 2023, by treating 200 raspberry plants of two different varieties (Vajolet and Glen Ample) with LALSTOP G46 WG at two different rates, 0.03g/plant and 0.06g/plant. These were compared to plants which were left untreated. The plants were grown for two months and then the number of plants showing reduced growth were counted for each strategy. Overall, the plant material was quite healthy with only a few dead plants detected in the whole area. From the dead plants, root pathogens *Pythium sp*. and *Fusarium sp*. were isolated, both of which debilitate early growth causing reduced yield and plant death. When left untreated, 6% of Glen Ample plants and 4% of Vajolet plants showed reduced growth, this was reduced to 2% where LALSTOP G46 WG was applied at 0.03g, and to 0% where applied at 0.06g in both varieties. These results suggest that the biological fungicide LALSTOP G46 WG can aid control of raspberry root diseases at the transplanting stage.

Introduction

On average, 20–40% of global crop production, including food crops, is lost annually due to pests and diseases (FAO, 2019). Pathogens, fungi, viruses, oomycetes, and bacteria, impart economically damaging diseases to fruits and vegetables, detrimentally impacting plant health, yield, and quality. The increasing popularity of techniques utilizing biological fungicides has emerged as a noteworthy trend, potentially mitigating the demand for chemical fungicides. A plethora of studies has already investigated the efficacy and effectiveness of biological fungicides, revealing promising outcomes. Notably, in Cambodia, the application of biological fungicides demonstrated a steady decline in citrus root rot, reaching approximately 60% (Kean et al., 2010). Similarly, bio-fungicides have exhibited a capacity to inhibit root rot development by over 50% in tomatoes (Hibar et al., 2006). When compared to an untreated control, biological products could reduce disease as well as chemical fungicides (Kean *et al*., 2010).

This comparison investigated the efficacy of LALSTOP G46 WG, a biological fungicide, by treating 200 raspberry plants of two distinct varieties, Vajolet and Glen Ample, at two application rates. Raspberries, with an intrinsic lifespan of 10 to 12 years, face premature reduction to a mere 5 years due to the Root Rot and Wilting Complex (RRWC). This complex is characterized by the rapid dissemination of inoculum, the persistent nature of oospores, and the inherent severity-worsening aspects of the infection process (Sapkota et al., 2022).

LALSTOP G46 WG, derived from the naturally occurring soil fungus *Clonostachys rosea* strain J1446, is a biological fungicide utilized in the cultivation of fruits, vegetables, and herbs. The historical recognition of *Clonostachys rosea* as an aggressive parasite on fungi dates back to the late 1950s, leading to subsequent attempts to harness its biological control potential in plant disease management (Shigo, 1958). Application of *C. rosea* has demonstrated promising results in controlling a myriad of diseases across various crops,

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including both soil-borne and seed-borne pathogens, as well as those affecting leaves, stems, flowers, and fruits (Funck Jensen et al., 2021).

This comparison in Pirkanmaa, Finland in 2023, included three strategies: Strategy 1, serving as the control without fungicide application for root disease control, Strategy 2 applying LALSTOP G46 WG at 0.03g/plant, and Strategy 3 applying it at 0.06g/plant. The plants were grown for two months and then the number of plants showing reduced growth were counted for each strategy.

Results

The findings reveal that the overall health of the plant material was good, with only a few instances of plant mortality across the entire area. Nonetheless, there was a higher prevalence of weakened plants in the untreated section for both Glen Ample and Vajolet, observed after a two-month growth period (Figure 3.3.1.2 and 3.3.1.3). Analysis of dead plants identified the presence of root pathogens, specifically *Pythium sp.* and *Fusarium sp.* (Figure 3.3.1.4), both of which can impact early plant growth, causing reduced yields and in some cases plant death. In the absence of treatment, 6% of Glen Ample plants and 4% of Vajolet plants exhibited diminished growth. This percentage was notably reduced to 2% with the application of LALSTOP G46 WG at 0.03g/plant, and further decreased to 0% when the application rate was increased to 0.06g/plant in both varieties (figure 3.3.1.1).

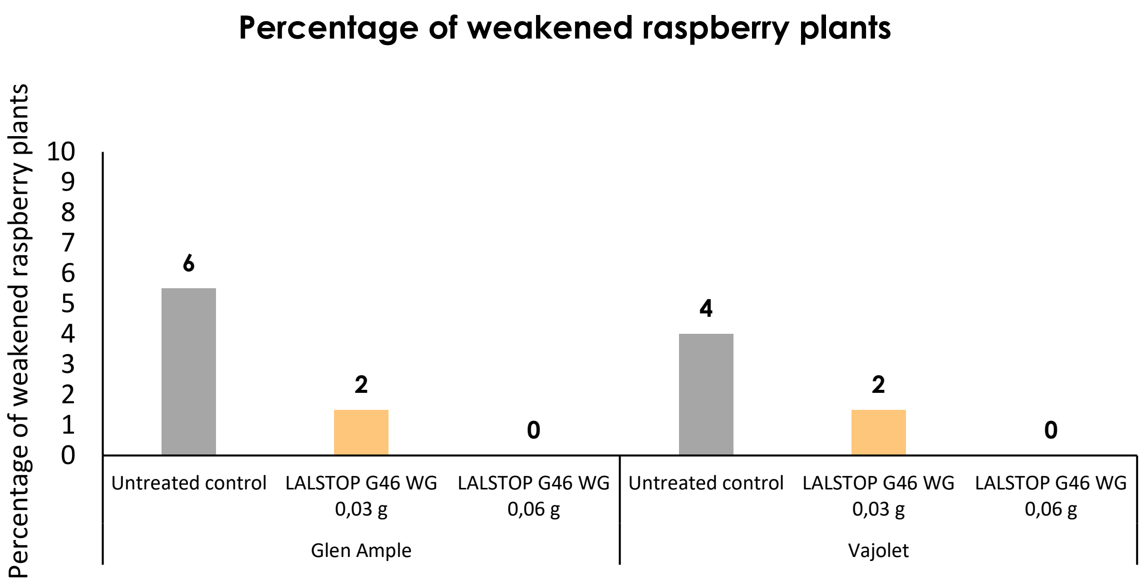

Figure 3.3.1.1: Percentage of plants in each treatment where growth was limited, and the plant appeared weak.

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Figure 3.3.1.2: Weaker 'Glen Ample' plants in the untreated area.

Figure 3.3.1.3: Weaker 'Vajolet' plants in the untreated area.

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Figure 3.3.1.4: Pythium sp. on growing media. Pythium was isolated from dead 'Glen Ample' plant.

Conclusions

The results from this comparison indicate that biological fungicide LALSTOP G46 WG, derived from *Clonostachys rosea* strain J1446, has potential to combat root pathogens, specifically Pythium sp. and Fusarium sp., contributing to the overall health of the raspberry plants. The use of LALSTOP G46 WG as a biological fungicide presents a promising strategy to enhance plant health while reducing reliance on chemical fungicides, contributing to sustainable and environmentally friendly agricultural practices. Continued research and adoption of such biological alternatives align with the global pursuit of effective and sustainable crop protection measures.

Methods

Strategies

This comparison was designed to demonstrate the control of key root diseases in raspberries (Fusarium, Pythium, Phytophthora) with a biological fungicide LALSTOP G46 WG (*Clonostachys rosea* J1446).

Table 3.3.1.1: Strategies included in this 'in-field' comparison

Strategy 1	**Control** – no fungicides for root disease control to be applied
Strategy 2:	**LALSTOP G46 WG** – 0.03g/plant
Strategy 3:	**LALSTOP G46 WG** – 0.06g/plant

Design

Two varieties were used, Vajolet and Glen Ample with 200 plants of each variety laid out in rows of 50 plants per row, per strategy. In strategy 2 and 3, LALSTOP G46 WG was applied twice, once just after planting and again 4 weeks later.

Crop health assessment

After two months of growth, the number of plants showing signs of poor heath were counted in each strategy. Dead plant material was used to isolate the plant pathogens responsible.

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3.4. Orchard

3.4.1. IPMWORKS: Using rock powder in the management Olive fly in Italy

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Summary

The olive fruit fly (*Bactrocera oleae)* is a key pest affecting olive trees in various regions globally. In light of the need for sustainable pest control methods, it is essential to explore preventive measures based on manipulating pest behaviour. The use of rock powder was compared to an untreated control on three olive farms during the 2022 and 2023 growing seasons in Monte Pisano, northern Italy, within an IPMWORKS hub. Assessments focused on the infestation levels of olive fly on 20 olives randomly selected from five trees per strategy. Rock powder is known for its potential to reduce olive fly infestation by reducing the capacity of the olive fly to recognise the olive fruit, as the rock powder changes the surface characteristics of the olive skin. On each farm, two areas were selected, one where the olive trees would receive one application of rock powder per year and one area where no pest control treatments were applied. In 2022 the level of damage was low, with most olives being recorded as intact across all three farms. As such, differences in the number of intact olives between the control and rock powder strategy tended to be small. In 2023, pest pressure was very high, with damage seen on most of the sampled olives. Damage increased dramatically between the first and second assessment across all three farms, possibly reflecting an increase in olive fruit fly due to conducive breeding conditions. On average a higher number of intact olives were found in rock powder treated areas compared with control areas at the second assessment across all three farms in 2023, however these differences were not found to be significant.

Introduction

Olive cultivation, a cornerstone of agriculture in many regions, faces persistent challenges from various pests, with the olive fruit fly (*Bactrocera oleae*) emerging as a prominent threat. The impact of this pest on olive orchards extends beyond direct fruit damage, influencing the quality and quantity of olive oil production (Malheiro *et al*., 2020). In pursuit of sustainable and eco-friendly alternatives to traditional pesticide-based approaches, researchers have turned their attention to the utilization of rock powders, such as kaolin and zeolite, as potential tools for managing infestations. Kaolin, a clay mineral, and zeolite, a crystalline aluminosilicate, have demonstrated unique properties that make them promising candidates for pest control. Kaolin, when applied as a protective barrier on plant surfaces, acts as a physical deterrent to insects, including the olive fruit fly (Glenn *et al.,* 2002). Zeolite, known for its adsorptive and ion-exchange capacities, holds potential for altering the environmental conditions around olive trees, influencing the behaviour of pests (Farina *et al.,* 2016). In recent years, research has highlighted the efficacy of kaolin in reducing the impact of various pests on crops, including olive trees (Isman, 2019). Additionally, studies on the use of zeolite in agriculture have shown promising results in modifying soil conditions and influencing the behaviour of insect pests (Zornoza *et al*., 2018). This comparison aims to demonstrate the effects of using kaolin and zeolite on olive trees in the containment of infestations caused by the olive fruit fly. The exploration of these rock powders as pest management tools aligns with the growing emphasis on sustainable and environmentally friendly practices in agriculture.

In this comparison, located in Monte Pisano, northern Italy, an area receiving no pest management treatments served as a control, to understand the natural infestation levels without any intervention. This

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was compared to an area utilising rock powder (kaolin and zeolite) once a year, guided either by the recommendations of a technician or based on the farm's experience.

Results

In 2022, all rock powder treatments were applied between the 5th and 7th July. In 2023, the treatments were applied between the 2nd and 7th July. Weather conditions differed between the two years, with very low water precipitation in 2022 and above-average wet conditions in 2023. For each monitored area, five trees were selected and labelled with unique codes. From each tree, 20 olives were collected, resulting in a sample of 100 olives from each area. The collected olives were then examined for infestation symptoms and categorised based on the symptoms seen.

Olive fly damage in 2022

At Bovoli, on average all 20 olives per tree remained intact in the control and 19.8 olives in the rock powder strategy on the 29th July. Equally on the 13th September 19.8 olives remained intact in the control and 20 for rock powder. By the 13th October, pest pressure had increased with an average of 17.4 olives intact in the control, and 19.2 olives where rock powder had been applied. At Lombardi, only two assessments were completed. On the 13th September an average of 18.8 olives were recorded as intact in the control and 15.8 where rock powder was applied. By the 13th October, an average of 15.6 olives were recorded as intact in the control, and 17.8 where rock powder was applied. At Zinetti, on the 29th July, on average 19.4 intact olives were recorded in the control, and 19.8 intact olives rock powder treated areas. Damage levels were similar on the 13th September with 19.2 intact olives in the control, compared to 19.8 with rock powder. Pest damage had increased by the 13th October with 16.2 olives recorded as intact in the control compared to 19.2 where rock powder was applied. Overall, damage caused by the olive fruit fly was low in 2022, with most olives being recorded as intact and damaged olives found on only a few trees in each sampling location (figure 3.4.1.1). Analysing the data from each assessment timing and farm using student T-Test found no significant difference between the two strategies ($P>0.05$). The cause of any damaged olives is summarised in table 3.4.1.1.

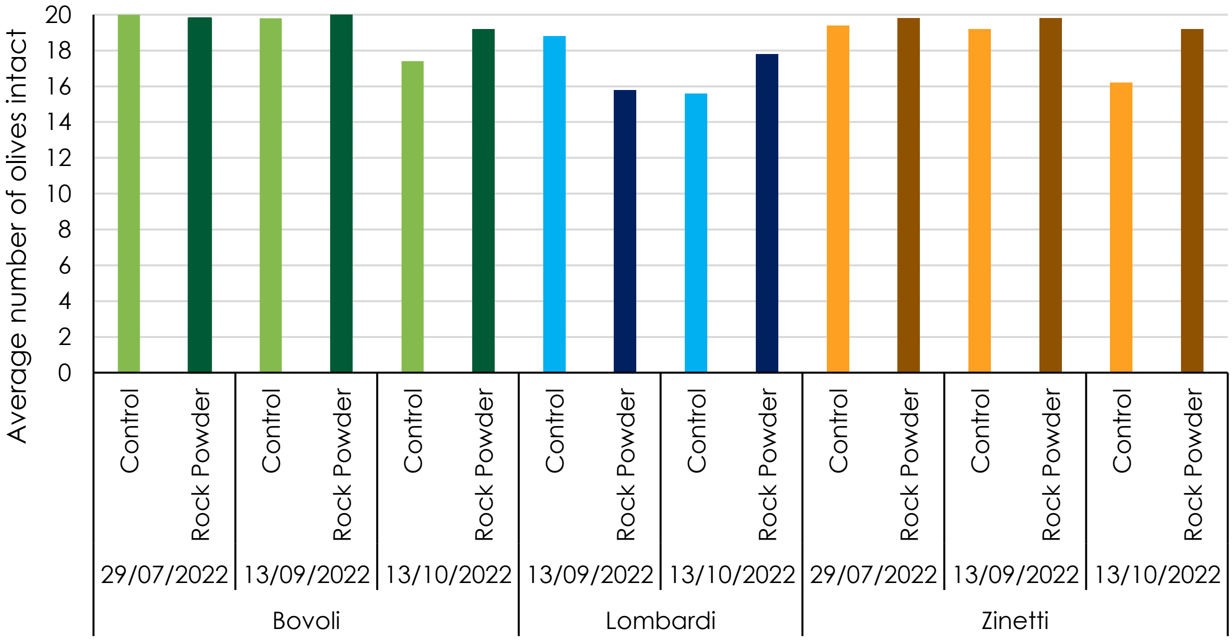

Figure 3.4.1.1: The average number of intact olives recorded per tree in each strategy per farm in 2022. Green bars represent values from Bovoli, blue Lambardi and brown Zinetti. The lighter shade being the control and darker shade where rock powder was applied.

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Olive fly damage in 2023

At Bovoli, an average of 17.2 olives per tree remained intact in the control and 16.2 olives in the rock powder strategy on the 20th July. Pest damage increased dramatically by the 9th September with only 4.6 olives intact in the control, and 7.4 where rock powder was applied. At the 4th October assessment, values were similar in each strategy with 8.2 olives intact in the control and 8.0 olives where rock powder had been applied. At Lombardi, 15.4 olives were recorded as intact on the 20th July in the control, compared to 11.8 where rock powder was applied. Again, pest pressure increased between assessments with only 2.4 olives recorded as intact in the control on the 11th September and 3.0 where rock powder applied. On the 4th October, 5.2 olives were recorded as intact in the control and 3.2 where rock powder was applied. At Zinetti, on the 20th July, 15.2 intact olives were recorded in the control and 14.2 with rock powder. As seen at the other farms, pest damage increased rapidly between assessments with only 3.4 intact olives in the control and 4.6 where rock powder applied on the 9th September. On the 4th October 5.2 olives were recorded as intact in the control compared to 5.6 where rock powder was applied. Overall, damage caused by the olive fruit fly was high in 2023, with damaged olives being found in most trees sampled (figure 3.4.1.2). The number of intact olives was slightly higher where rock powder was used on the 9th September at Bovoli, 11th September at Lombardi and both the 9th September and 4th October at Zinetti, however, analysing the data from each assessment timing and farm using student T-Test found no significant difference between the two strategies ($P>0.05$). The cause of any damaged olives is summarised in table 3.4.1.2.

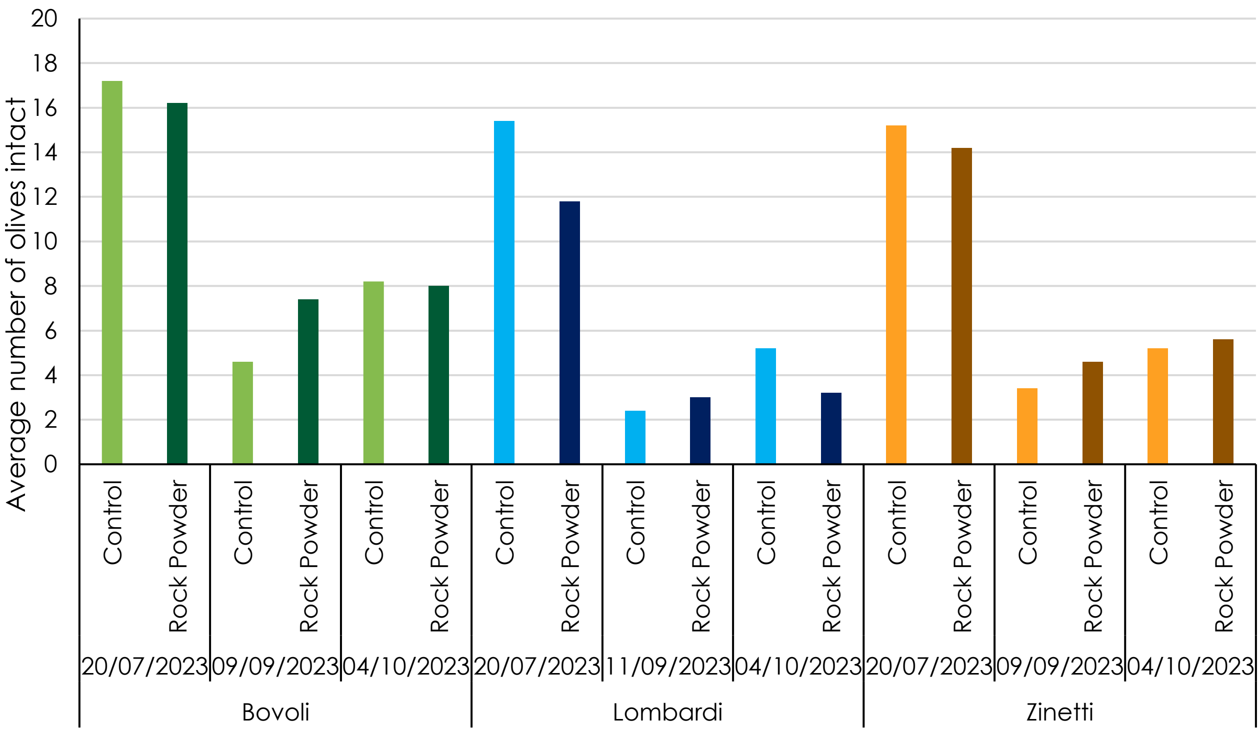

Figure 3.4.1.2: The average number of intact olives recorded per tree in each strategy per farm in 2023. Green bars represent values from Bovoli, blue Lambardi and brown Zinetti. The lighter shade being the control and darker shade where rock powder was applied.

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Table 3.4.1.1: Olive damage classifications for the control and rock powder strategies at each site and assessment in 2022. Presented as an average of five trees.

		Strategy	Total olives assessed per tree	Intact Olives	Egg inside olive	First larval stage - live	First larval stage - dead	Second larval stage - live	Second larval stage - dead	Third larval stage - live	Third larval stage - dead	Pupa in olive	Presence of flicker hole	Fly bites but no egg	Lasioptera berlesiana present
Bovoli	29/07/2022	Control	20	20	0	0	0	0	0	0	0	0	0	0	0
		Rock Powder	20	19.8	0	0	0.2	0	0	0	0	0	0	0	0
	13/09/2022	Control	20	19.8	0	0	0.2	0	0	0	0	0	0	0	0
		Rock Powder	20	20	0	0	0	0	0	0	0	0	0	0	0
	13/10/2022	Control	20	17.4	0	0	1	0	0	0	0.2	0	0	1.4	0
		Rock Powder	20	19.2	0	0	0.2	0	0	0	0.2	0	0	0.4	0
Lombardi	13/09/2022	Control	20	18.8	0.2	0	0.6	0	0.2	0	0	0	0	0.2	0
		Rock Powder	20	15.8	0.2	0	1.2	0	1.6	0	0.6	0	0.6	0	0
	13/10/2022	Control	20	15.6	0	0	1.4	0	1	0	1.4	0	0	0.6	0
		Rock Powder	20	17.8	0	0	0.8	0	1.4	0	0	0	0	0	0
Zinetti	29/07/2022	Control	20	19.4	0	0	0.4	0	0	0	0	0	0	0.2	0
		Rock Powder	20	19.8	0	0	0	0	0	0	0	0	0	0.2	0
	13/09/2022	Control	20	19.2	0.2	0	0.6	0	0	0	0	0	0	0	0
		Rock Powder	20	19.8	0	0	0.2	0	0	0	0	0	0	0	0
	13/10/2022	Control	20	16.2	0	0	0.6	0	1.2	0.2	1.6	0	0.2	0	0
		Rock Powder	20	19.2	0	0	0.2	0	0.2	0	0.4	0	0	0	0

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Table 3.4.1.2: Olive damage classifications for the control and rock powder strategies at each site and assessment in 2023. Presented as an average of five trees.

		Strategy	Total olives assessed per tree	Intact Olives	Egg inside olive	First larval stage - live	First larval stage - dead	Second larval stage - live	Second larval stage - dead	Third larval stage - live	Third larval stage - dead	Pupa in olive	Presence of flicker hole	Fly bites but no egg	Lasioptera berlesiana present
Bovoli	20/07/2023	Control	20	17.2	1.2	0	1	0	0	0	0	0	0	0.6	0
		Rock Powder	20	16.2	1.2	0.4	1	0	0	0	0	0	0	1.2	0
	09/09/2023	Control	20	4.6	0.2	1.4	4	0.8	4.8	0.2	2.4	0.6	0.6	0.4	0
		Rock Powder	20	7.4	0	1.8	4.2	0.4	3.4	0.2	1.8	0.2	0.4	0.2	0
	04/10/2023	Control	20	8.2	0.2	0.2	2	0	2.8	0.4	0.6	1.6	3.6	0.4	0
		Rock Powder	20	8	0	0	2.2	0.25	1.8	1.6	1.2	2.8	2	0.2	0
Lombardi	20/07/2023	Control	20	15.4	0.8	0	2.8	0	0	0	0	0	0	1	0
		Rock Powder	20	11.8	1	0	4.2	1	0.8	0	0	0	0	1.2	0
	11/09/2023	Control	20	2.4	0.6	0.4	1.8	0.2	3.8	0.8	1.8	2.4	5	0.8	0.6
		Rock Powder	20	3	0.2	0.6	2.6	1.6	3.2	2	0.6	1	4.4	0.8	0
	04/10/2023	Control	20	5.2	0.4	0.4	1.2	0.6	0.8	1.2	0.4	4.2	5.4	0.2	0.4
		Rock Powder	20	3.2	0	0	0.4	0.6	1	2.2	1.2	2.4	8.8	0.2	0.4
Zinetti	20/07/2023	Control	20	15.2	1.4	0.2	1.2	0.2	0	0	0	0	0	1.8	0
		Rock Powder	20	14.2	1.4	1.6	2.2	0	0	0	0	0	0	0.6	0
	09/09/2023	Control	20	3.4	0.4	1	2	0.6	2.8	0.2	0.6	1	7.4	0.6	0
		Rock Powder	20	4.6	0.8	1.8	2.4	0.4	2.2	0.2	1.8	1.4	3.8	0.6	0
	04/10/2023	Control	20	5.2	0.2	0	2.8	0.8	2	0.6	0.8	1.2	4.6	1.8	0
		Rock Powder	20	5.6	0.2	0	1.4	0.2	2.8	1.4	3.4	2.4	2	0.6	0

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Conclusion

The pest pressure differed significantly in the two seasons evaluated in this comparison. In 2022 the level of damage was low, with most olives being recorded as intact across all three farms. Differences in the number of intact olives between the control and rock powder strategy tended to be small. In 2023, pest pressure was very high, with damage seen on most of the sampled olives. Damage increased quite dramatically between the first and second assessment across all three farms, possibly reflecting an increase in olive fruit fly due to conducive breeding conditions. Rock powder did achieve a higher number of intact olives than the control at the second assessment across all three farms, however these differences were not found to be significant. Therefore, in this comparison, the benefit of rock power on olive fruit fly was not clear and the benefits not fully realised. Further research is needed to understand the best conditions and timing of application of rock powder before this strategy can be fully implemented into IPM plans.

Methods

Strategies

This comparison was conducted to demonstrate the impact of employing kaolin and zeolite, two types of rock powder, on olive trees for controlling infestations caused by the olive fruit fly, *Bactrocera oleae*. Application of rock powders to olive trees could reduce the capacity of olive flies to identify the olives, consequently limiting the damage caused. On three farms in both 2022 and 2023, an area of the orchard was selected and left untreated as a control and compared to an area where rock powder was applied between the 5th and 7th July 2022 and between the 2nd and 7th July in 2023.

Olive sampling

Sampling was conducted for each of the monitored areas. Five trees were selected in each area and labelled with unique codes. From each tree, 20 olives were collected, resulting in a sample of 100 olives from each area per farm. The sampled olives were then inspected by a technician in the laboratory for infestation according to the protocol developed by Researcher Ruggero Petacchi. Sampling activities at each farm started at the beginning of olive fly infestation and lasted until the olive harvest, typically from October to November. During the comparison olives were collected three times, to monitor the temporal variation in olive fly infestation.

The first stage of olive inspection involved visually separating the sampled olives that had no olive fly bites, hence were healthy (intact), from those potentially infested (with bites or other symptoms). Once separated, the olives were dissected using a scalpel and inspected under a stereomicroscope to determine the type of infestation, which was recorded on an Excel sheet. The various case histories were then noted:

- egg: presence of an egg inside the olive;
- larva: presence of the oil fly larva at a certain larval stage, in particular:
    - presence of live larva at the first larval stage;
    - presence of dead larva at the first larval stage;
    - presence of live larva in the second larval stage;
    - presence of dead larva at the second larval stage;
    - presence of live larva at the third larval stage;
    - presence of dead larva at the third larval stage;

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- pupae: presence of the pupa inside the olive;
- presence of flicker (exit) hole;
- presence of fly bites in which the egg is not found.

• presence of *Lasioptera berlesiana* larvae inside the olive.

Data has been summarised by calculating the total number of olives in each category, per strategy, per assessment, per farm.

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3.5. Outdoor vegetable

3.5.1. IPMWORKS: Mulching in zucchini, a comparison between polyethylene plastic and biodegradable mulch in Belgium

Authors: De Mey, J.[1], Dearlove, E[2] and Francis, C.[2]

1. Inagro, Belgium
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Summary

Mulching is widely used in fruit and vegetable cultivation to suppress weed growth, conserve moisture and improve soil health. Historically, a polyethylene mulch has been used due to its low cost and benefits to crop growth. However, the use of petroleum-based plastic mulches raises many environmental concerns due to the persistence of plastic waste in the environment and the high carbon emissions from plastic production. In an effort to turn away from plastic mulches, while retaining effective weed suppression and other beneficial factors associated with mulching, several alternatives have been investigated, including biomulch. Biomulch is a biodegradable fabric or film that offers the same benefits as plastic mulch but has a lower environmental impact. In this comparison, carried out in Hooglede, Belgium in 2023, an area utilising biomulch for zucchini production was compared to plastic mulch by observing the biodegradability and taking green cover measurements. There were negligible differences between the two during the comparison, suggesting that biomulch could be a useful alternative to plastic mulch.

Introduction

Mulching is a widely used agricultural practice aimed at conserving soil moisture, suppressing weed growth, and improving soil health. A polyethylene (PE) mulch is typically used in intensive vegetable and fruit cultivation (Lamont, 2005), partly because of its low cost and ability to increase yields and improve crop growth (Cirujeda et al., 2012). Zucchini crops are very sensitive to weed infestations, due to increased competition with the crop (Coleman et al., 2015). The use of mulch reduces weed populations by suppressing weed growth. A study on Zucchini in Brazil, found that, compared to the non-mulched treatment, mulches were effective in reducing weed infestation (95%), increasing yield (36%) and improving water-use efficiency (94%) (Silva et al. 2020). Mulches therefore provide an effective, non-chemical weed control option for fruit and vegetable cultivation.

Many growers have started considering alternatives to petroleum-based plastic mulches because of environmental concerns. Several such alternatives to PE mulches exist, including organic mulches derived from agricultural or urban waste and byproducts, e.g., straw and newspaper mulches (Monks et al., 1997), paper-based mulches, and biodegradable fabrics and films (Miles et al., 2012). Of these options, biofabrics and bioplastic films have demonstrated the greatest potential as commercial alternatives to PE mulch (Miles et al., 2012). Unlike plastic mulch, biomulch offers several environmental benefits, making it an attractive option for sustainable agricultural practices. One of the primary advantages of biomulch over plastic mulch is its biodegradability. Unlike plastic, which can persist in the environment for hundreds of years, biomulch decomposes naturally over time, reducing the accumulation of plastic waste in

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agricultural fields and ecosystems (Smith, 2019). Additionally, the decomposition of biomulch adds organic matter to the soil, improving soil structure, nutrient content, and microbial activity (Miles & Hartz,2000). Furthermore, the production and disposal of plastic mulch contribute to carbon emissions and pollution, whereas biomulch production typically has a lower carbon footprint and can be recycled or composted after use, closing the loop on resource utilization (Garlock & Boesch 2014).

In this comparison, utilisation of a biomulch was compared to a plastic mulch, in the production of zucchini in Hooglede, Belgium in 2023. The percentage of green cover was assessed on three separate occasions to highlight any differences in ground cover between the two strategies.

Results

The degradation of biomulch in comparison to conventional plastic mulch appeared similar for the duration of the comparison and could not be discriminated by visual assessment. Although found to be significant by students two sample T-Test, the difference in green canopy cover between the biomulch and conventional plastic mulch was very small when assessed on three separate occasions (table 3.5.1.1). As green cover would include the zucchini plants and any weeds, the lack of any large differences between the two strategies indicates that crop growth and weed cover was similar between the two strategies.

	Average green canopy cover (%)		
	05/07/23	**02/08/23**	**16/08/23**
Biomulch	58.3	91.2	91.2
Conventional plastic mulch	61.1	89.4	89.4
Students Two Sample T-Test P Value	*0.012*	*0.015*	*0.011*

Table 3.5.1.1: Average green canopy cover for the biomulch and conventional plastic mulch cropping areas and student two sample T-Test P values.

Conclusions

The comparison between biodegradable mulch (biomulch) and conventional plastic mulch revealed no obvious differences in their degradation over the study period, as determined by visual assessment. Furthermore, the average percentage of green cover in zucchini plants, measured on the 5th July, 2nd August and 16th August, showed negligible differences between the two mulch types. This indicates that crop growth was not significantly impacted by the use of biodegradable mulch compared to plastic mulch. These results suggest that biodegradable mulch could be used as a viable alternative to conventional plastic mulch without compromising crop production and weed control. Biodegradable mulch performed similarly to plastic in terms of supporting plant growth, but offers environmental benefits by reducing long-term plastic waste and pollution. Critically, switching to a biodegradable mulch is therefore a viable alternative to PE, without the need for any increase in herbicides to manage weeds in the crop.

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Methods

A field site was located in Belgium in a crop of zucchini. Variation in vegetative growth for previous crops grown in the field was examined using normalized difference vegetation index (NDVI) images. Prior to the comparison starting, the field showed variation in NDVI between East and West (figure 3.5.1.1). Most of the field was covered with PBAT based biomulch and two rows within the indicated strategy block in figure 3.5.1.2 were covered in PE plastic mulch.

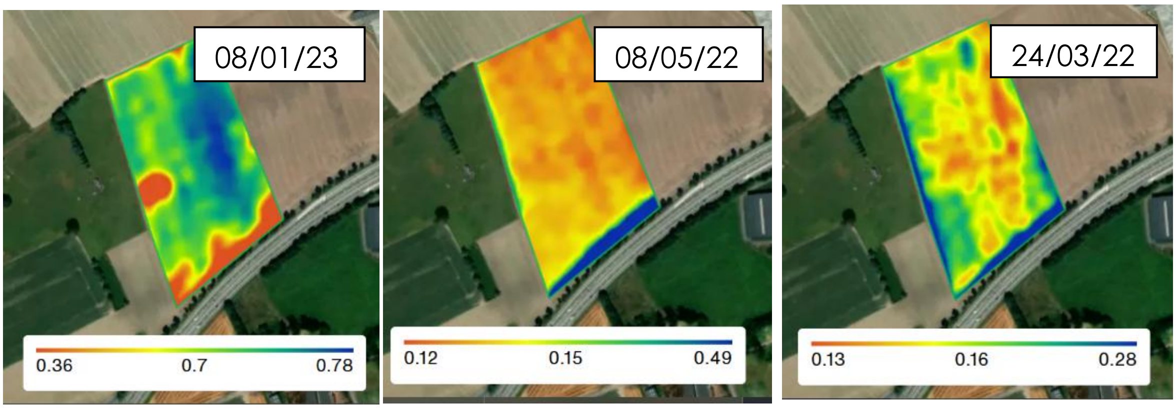

Figure 3.5.1.1. Normalized difference vegetation index (NDVI) of zucchini field used in a mulch comparison in Belgium prior to the comparison taking place. Images sourced from https://www.datafarming.com.au/.

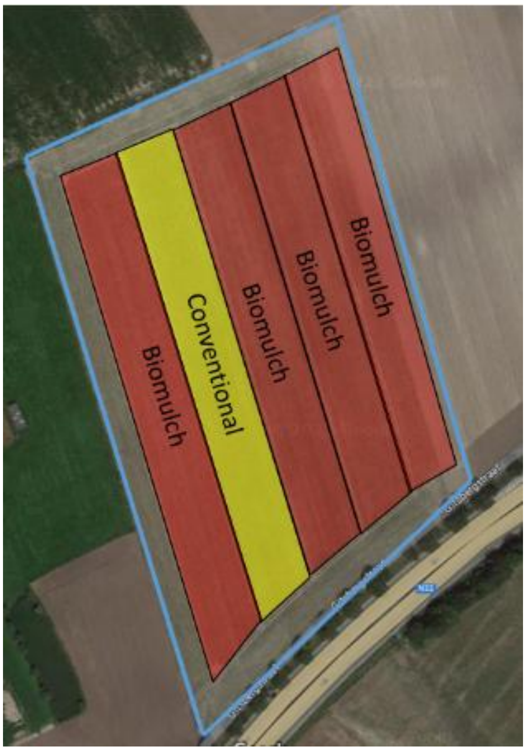

Figure 3.5.1.2. Comparison design across the 5.4ha field comparing conventional plastic mulch and biomulch.

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Green canopy measurements

On the 5th July, 2nd August and 16th August 2023 mulch degradation was assessed by visually inspecting each strategy area. Images were taken in 8 locations equally distributed within each strategy. At each location, four images were taken to quantify the percent canopy cover of live green vegetation. Images were uploaded to Canopeo (2024). Canopeo, is a digital image-based software for canopy measurement, developed by Oklahoma State University and available for Android and iOS devices (http://www.canopeoapp.com). It is an automatic color threshold (ACT) deduction software and measures the green ground cover based on red to green (R/G), blue to green (B/G) and an overload green index (2G – R – B) (Patrignani and Ochsner 2015).

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3.5.2. IPMWORKS: Using mechanical weeding in a crop of pod peas to reduce weed pressure in Finland

Authors: Kallela, M.[1], Francis, C[2] and Jones, I.[2]

1. Proagria, Finland
2. ADAS, England

Summary

Mechanical weeding is an effective weed control strategy being used in a range of different row crops as an alternative to herbicide use. There are many different types of mechanical weeders, but each usually involves the use of tillage implements such as harrows, weeders and cultivators. These implements uproot and/or bury weeds growing between the crop rows. In this comparison, carried out in Alvettula, Finland, in 2023, a 2.01ha field of pod peas was divided into two sections: 0.75ha was treated with a chemical herbicide on the 25th May, whereas 1.26ha was harrowed on the 28th June. An assessment of the weed species present in each area was completed on the 5th July. As conditions were dry after drilling, the pod pea crop suffered from drought and plant biomass was reduced. As such, pod peas did not compete very well with the weeds. Both areas had weed species present during the assessment, with 9 species identified in the chemically treated area. However, the harrowed area had a significantly higher presence of weeds within the crop, with 19 different weed species identified. This was due to heavy rainfall immediately after the harrow was used, meaning new weeds emerged from the soil movement. It is well known that mechanical weeding can achieve good results, this comparison has highlighted that particular attention should be paid to the conditions around the time of the weeding to ensure success.

Introduction

Pod peas are a vital vegetable crop loved for their nutritious seeds and succulent pods. Weed infestations, however, pose a significant threat to yield and quality of pod peas. Weeds have been shown to cause between 37.3 to 64.4% reduction in pea yields (Tewari *et al.*, 1997; Banga *et al.*; 1998 and Harker, 2001). Weed control in pod pea cultivation is a critical aspect of ensuring optimal yields and maintaining crop health. Several studies have highlighted the importance of weed management in pea crops, as weeds can compete for resources, reduce yield, and impede harvesting efficiency (Smith et al., 2018; Blackshaw et al., 2020).

A number of weed control methods are being explored by farmers and researchers in response to these challenges, with a particular focus on mechanical and chemical methods. The choice between mechanical and chemical weed control methods has been a subject of considerable research and discussion within the agricultural community. While chemical weed control has historically been a widely adopted approach due to its efficiency, and efficacy in eradicating a broad spectrum of weeds (Jabran et al., 2017), concerns over the environmental impact (Owen et al., 2019), herbicide resistance (Délye et al., 2019), and the potential presence of residues in the final produce have led researchers to explore alternative methods, with mechanical weed control emerging as a promising alternative.

Mechanical weed control methods, including cultivation and hoeing, have gained prominence as sustainable alternatives. Edwards (1987) argue that mechanical weed control methods can

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contribute to sustainable agriculture by minimizing the reliance on chemical inputs. The benefits of mechanical weed control extend beyond weed suppression, encompassing improvements in soil structure and water retention. Unlike chemical herbicides, these practices avoid soil compaction and enhance water infiltration, fostering an environment conducive to pea pod development (Hatfield, & Prueger, 2015). Mechanical weed control practices, when implemented correctly, can be cost-effective and labour efficient. Farmers can achieve comparable or improved weed control results with reduced dependency on expensive herbicides, leading to economic benefits (Fawcett & Towery, 2002). The use of mechanical weed control also minimizes the presence of chemical residues in pea pods. This is crucial for ensuring food safety and meeting consumer demands (Benbrook *et al*., 2002). Mechanical weed control methods also contribute to the preservation of biodiversity by avoiding the indiscriminate elimination of plant species. This aligns with the principles of agroecology, promoting a more balanced and resilient agricultural ecosystem (Altieri, 1999). Understanding the benefits of mechanical weed control in pea pods compared to chemical weeding is crucial for advancing sustainable and environmentally friendly agricultural practices.

This ‘in-field’ comparison was conducted in Alvettula, Finland in 2023. A 2.01ha field was divided into two separate areas. An area of 0.75 ha drilled on the 20th May, used chemical herbicides, while a larger area of 1.26ha drilled on the 7th June 2023 used harrowing to control the weeds. To compare the success of each strategy a weed count assessment was conducted.

Results

The field, divided into two areas, underwent contrasting strategies, a 0.75ha area treated with chemical herbicides on the 25th May and a 1.26ha area subjected to harrowing on the 28th June. A plant count and weed assessment was conducted on the 5th July. The pea pod crop suffered from dry conditions after sowing and as such the plants remained small and were not very competitive against weeds. The average number of pea pod plants was slightly lower in the area that was harrowed than where chemical control was used, however this was not found to be a significant difference ($P>0.05$) (table 3.5.2.1).

Despite utilising weed control strategies in both areas, several weed species were recorded (table 3.5.2.1). Where chemical control was used, 9 weeds species were present, with a particularly high abundance of common nippleworth (*Lapsana communis*) and field pansy (*Viola arvensis*). However, the harrowed section had a higher weed burden than the chemical with 19 weeds species identified, most were present at less than 10 plants/m^2, the only exceptions being common nippleworth, field pansy and red dead nettle (*Lamium purpureum*). The number of plants in the harrowed area was found to be significantly higher than the chemical control for speedwell (*Veronica* sp.), goosefoot (*Chenopodium album*), red dead-nettle and shepherd’s purse (*Capsella bursapastoris*). The higher weed burden in the harrowed strategy is thought to be due to heavy rainfall soon after the harrowing process, resulting in a weed emergence peak.

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Table 3.5.2.1: Pod pea plant and weed species count completed on the 5th July 2023 in the harrowed area and area where chemical control was used. Values represent the number of plants in 1m². Data has been analysed using two-tailed students T-Test.

	Harrowing (number of plants/m²)	Chemical Control (number of plants/m²)	Two-tailed Students T-Test P Value
Pod pea	30.4	40	0.17
Common nippleworth, *Lapsana communis*	51.6	33.2	0.29
Common fumitory, *Fumaria officinalis*	6	1.6	0.12
Field pansy, *Viola arvensis*	44.8	24.4	0.14
Speedwell, *Veronica spp.*	5.2	0	**0.04**
Dandelion, *Taraxacum Asteraceae*	0.8	0.4	0.66
Goosefoot, *Chenopodium Amaranthaceae*	7.2	0	**0.05**
Red dead-nettle, *Lamium purpureum*	47.2	4.8	**0.02**
Annual bluegrass, *Poa annua*	0.8	0.4	0.56
Shepherd's purse, *Capsella bursa-pastoris*	2.4	0	**0.04**
Field pennycress, *Thlaspi arvense Brassicaceae*	2.8	0	0.05
Mayweed, *Tripleurospermum*	9.2	1.2	0.06
Cornflower, *Centaurea cyanus*	0.4	0	0.33
Mugwort, *Artemisia vulgaris*	0.4	0	0.33
Marsh cudweed, *Gnaphalium uliginosum*	0.8	0	0.15
Spurry, *Spergula*	1.6	0	0.21
Couch grass, *Elymus repens*	0.4	2	0.23
Creeping thistle, *Cirsium arvense*	0.4	0	0.33
Cockspur, *Echinochloa crus-galli*	0.4	0	0.33
Greater plantain, *Plantago major*	0.8	0	0.33

Conclusions

In the pursuit of effective weed control in pod pea cultivation, the comparison between mechanical and chemical weeding methods has provided valuable insights. The experiment conducted shows the practical challenges associated with both approaches. As the pea pod crop suffered from drought causing stunting, it was not very competitive against weeds, enabling weed populations the space to establish within the crop, creating high weed pressure. Even with the use of chemical herbicides high numbers of common nippleworth and field pansy remained. Although harrowing initially reduced the weed burden, the high rainfall that followed created a conducive environment for weed growth and so many new weeds emerged shortly afterwards. Given the high weed burden, it's likely that a combination of both mechanical and chemical control as part of an integrated weed control strategy would have been beneficial here. There are several examples of successful mechanical weeding strategies in the wider literature, leading to a reduction in herbicide usage which helps to slow down herbicide resistance development, as well as limiting the amount of herbicide residues on food and reaching water courses. This comparison has highlighted the importance of monitoring the outcome of a given strategy and incorporating chemical herbicides where justified in an integrated pest management approach.

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Methods

Strategies

This comparison was designed to demonstrate the effect of mechanical weeding (harrowing) compared to chemical herbicides to reduce weed burden in a crop of pod peas. A 2.01ha field was divided into two areas.

Table 3.5.2.2: The two strategies demonstrated in this 'in-field' comparison to evaluate control of weeds in a crop of pod peas.

Strategy 1:	Chemical herbicides were used
Strategy 2:	No chemical herbicide applied, just harrowed

Design

This comparison was conducted on a farm in Finland. Strategy 1 (0.75 ha) was drilled on the 20th May 2023 and chemical herbicides were applied on the 25th May. Strategy 2 (1.26 ha) was drilled on the 7th June and harrowed on the 28th June.

Figure 3.5.2.1: Image showing the layout of the 'in-field' comparison

Plant and Weed Counts

Using a 0.25m2 quadrat, all pea pod plants were counted and weed species were identified and counted within the quadrat, in 10 quadrats per strategy.

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4. Conclusions

The implementation of 'in-field' comparisons in this project provided demonstrations of IPM strategies for use at demonstration events, while also generating data on the chosen strategy. This enable quantitative reports to be written on the chosen strategies which can be shared within the IPMWORKS Hubs and more widely on the IPMWorks toolbox, ensuring that the reach of the demonstration extends much further than just those who attend events.

To carry out 'in-field' comparisons, host farmers need to be engaged in the subject being demonstrated and happy to carry out two different strategies in the same field. Careful selection of the field and crop is vital, aiming to choose an area that is as consistent as possible to prevent underlying differences impacting on the data collection. More guidance on this is available in the IPMWORKS guidelines for 'in-field' comparisons of alternative IPM strategies for demonstration purposes (milestone 3.1). This approach also requires good communication between the advisor providing guidance and the host farmer, to ensure that it is clear in the field what strategies have been carried out and where. Collection of data on pest levels in each strategy and where possible yield, can then help to quantify the effect of a given strategy.

Carrying out a new strategy first in a small area of a field, if successful, can give a grower the confidence to use the new strategy across the whole farm. In doing so, 'in-field' comparisons play a vital role in the uptake of IPM and reduction of pesticide use, leading to more sustainable agricultural practices.

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