The combined effects of perimeter trap crops and semiochemical attractants on the management of pea and bean weevil and bruchid beetle in faba beans

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Introduction

Faba bean (*Vicia faba* L.) is an essential UK and European legume crop for both human and animal nutrition and in agroecosystems as a nitrogen-fixing break crop. Grain yield and quality however may be significantly reduced by damage caused by pea and bean weevil (*Sitona lineatus*) and bruchid beetle (*Bruchus rufimanus*). Reduction in yield occurs as pea and bean weevil larvae feed on the plant's nitrogen-fixing root nodules, which additionally limits benefits to the following crop. Bruchid beetles on the other hand cause damage to faba bean seeds as larvae bore through during feeding, before emerging as adults. These pests have become increasingly difficult to manage in conventional agricultural systems due to restrictions in agrochemical usage, resistance to existing insecticides and climate change. In organic agricultural systems there are very few effective techniques to manage these pests at present. In the UK there has been a sustained increase in infestation of faba beans by bruchid beetles, and steady movement of the pest to more northern latitudes as mean temperature during the growing season has increased over the last 20 to 30 years. Black bean aphid (*Aphis fabae*) is another common pest, causing damage to bean stems through direct feeding. This damage results in wilting and reduced pod-fill, which in turn reduces yields. Aphids also act as a vector for a number of viruses including bean leaf roll virus (BLRV) and bean yellow mosaic virus (BYMV) with honeydew produced by the aphids encouraging moulds and *Botrytis.* Aphid damage is generally managed through the application of insecticides.

In countries such as France, production of faba beans has declined in part due to difficulty in achieving the quality required. As the area of faba beans increases in countries such as Sweden, Finland and Denmark, bruchid beetles have increasingly become a barrier to the production of high-quality crops for human consumption. Pea and bean weevil populations in the UK have become more resistant to pyrethroid insecticides in recent years and there is some evidence that this is also the case for bruchid beetles. Sustainable solutions using ecological practices may provide effective integrated pest management (IPM) strategies but require thorough testing under commercial-scale field conditions. One such IPM approach is to use an earlier-sown perimeter trap crop to attract beetle pests and prevent infestation of the main crop. Trap cropping is a traditional technique used to manipulate agricultural ecosystems, providing differential conditions for oviposition and feeding, and diverting and intercepting target species to reduce impact in the main crop (Seidenglanz *et al*., 2022; Shelton and Badenes-Perez, 2006).

There is strong evidence that sowing date of faba bean influences the level of damage caused by bruchid beetles and pea and bean weevils, mainly due to differences in availability of food and oviposition resources at key insect life stages. Bruchid beetles may be more attracted into earlier developing host crops as they emerge from overwintering sites, where they are able to feed and oviposit, sparing later sown crops from the highest levels of infestation and ensuing damage (Ward, 2018).

Delobel and Delobel (2006) showed that bruchid beetle larvae were able to feed on and complete their lifecycle in several wild vetch species as well as faba beans, indicating an ability to reach sexual maturity following pollen feeding in both *Lathyrus* and *Vicia* genus. Several vetch species were found to host *B. rufimanus*, including red vetchling, Venetian vetchling, sainfoin vetch, wandering vetch, winter/ fodder vetch, Bithynian vetch, hairy yellow vetch, smooth yellow vetch, purple broad vetch and Hungarian vetch. Although the main hosts of *S. lineatus* are peas and beans, they are also similarly reported to feed and reproduce on lucerne, lupins and field vetch, providing opportunities to test the effectiveness of species mixtures as trap crops for both pests. There is also evidence for the establishment of trap crops as an attractant and resource-rich habitat for natural enemies including predators and parasitoids, therefore improving biological control of pest species (Parolin *et al*., 2012; Sarkar *et al*., 2018). Vetch species including hairy vetch have been shown to provide habitat for ladybirds (Coccinellidae), with other flowering plants attracting parasitic wasps (Apocrita) and hoverflies (Syrphidae); all major predators of black bean aphid (Ben-Issa *et al.,* 2017).

Reduction in damage by pea and bean weevils can also be obtained by delaying sowing (Cárcamo *et al*., 2018). For *S. lineatus* and *B. rufimanus* the use of perimeter trap cropping may provide a useful solution to help reduce damage to crops, where early sown host crops or other legume mixtures are sown around the field margins to attract adults as they emerge from overwintering sites and provide alternative locations for feeding and oviposition.

In conjunction with a trap crop approach to beetle control in field beans, this project seeks to investigate the added effect of a pheromone attractant for pea and bean weevils (Smart *et al*., 1994) and plant volatile attractants for bruchid beetles (Bruce *et al*., 2011) to increase the attractiveness of the trap crop.

This project seeks to develop an IPM solution in faba beans that can help growers to move from high insecticidal inputs towards cultural and organic production techniques. The objectives are to identify the benefits of legume-based perimeter trap crops, combined with the targeted placement of compounds derived from naturally occurring pheromones and plant volatiles, as measures to reduce the impact of the pea and bean weevil (*Sitona lineatus*) and the bruchid beetle (*Bruchus rufimanus*) on faba bean yield and grain quality. The effect of the trap crops on other crop pests such as aphids will also be studied, and added ecological benefits to agricultural systems contributed by the trap crops, particularly for beneficial insects, will be evaluated. The proposed measures will provide a solution that may be easily implemented by growers and encourage ecological approaches to faba bean production.

Methods

Glossary

Key term	Description
Conventional farm	A farming system based on the use of agrochemicals to maximise crop production.
Regenerative farm	An evolution of conventional farming focussing on reducing inputs to improve biodiversity.
Trap crop	An area of crop sown alongside another crop which is more attractive to pests and disease than the actual crop
Legume rich margin	An area at the edge of a field acting as a barrier for pests and diseases which includes many species of legumes

Study Area & Field Locations

Across the 3 years of the project, seven sites in Cambridgeshire, UK were studied (Figure 1). In each year, one conventional farm with early spring sown trap crop which followed a standard spray programme was assessed, in addition to a regenerative farm which had a long history of not applying insecticides. In 2021, another 'mixed' farm was included which followed an approach between the two regimes.

Figure 1. Locations of all trial sites in all years of the project, 2021-2023.

Table 1. Details of trial sites across all years, 2021-2023.

Site reference	Location (OS grid reference)	Cultivation System	Whole farm spray regime	Insecticides applied on trap crop fields	Crop	Trap crop details	Crop sown
ABB 23	TL 33595618	Direct drill	No insecticides	0	Spring Beans	Long-term legume rich field margin	3rd March 2023
ALC 23	TL 19937397	Plough	Standard spray programme	1	Spring Beans	Mid Feb-sown strip of spring beans	28th Feb 2023
PAP 22	TL 27617836	Direct drill	No insecticides	0	Spring Beans	Long-term legume rich field margin	1st April 2022
WW 22	TL 21368417	Plough	Standard spray programme	2	Spring Beans	Spring beans sown in January	21st March 2022
PAP 21	TL 27696192	Direct drill	No insecticides	0	Spring Beans	Long term legume rich margin	10th April 2021
MID 21	TL 16006430	Plough-based	Insecticides only if required	0	Winter Beans	Mix of wild bird mix and lucerne	14th October 2020
HH 21	TL 28127616	Plough-based	Standard spray programme	0	Spring Beans	Spring beans sown in January	5th April 2021

Pest pheromone and plant volatile stations

Pea and bean weevil (S. lineatus) pheromone bait stations

S. lineatus (pea and bean weevil) pheromone baited stations were placed within the trap crops and secured by canes at ground level (Figure 2A). The bait stations were modified boll-weevil traps with semi-circular holes in the base to allow weevils to enter the base of the station and crawl into the trap, where they were captured in a plastic bulb at the apex of the trap. Lures contained 25*ul* of the *S. lineatus* aggregation pheromone, 3,5-Heptanedione, 4-methyl, measured into plastic flip-top vials. The baited vials were secured to the inside of the green plastic cone. At each site, 40 stations were placed in the trap crops, arranged in two rows, approximately 10 metres apart. The traps were checked every 2 weeks and the number of weevils captured was recorded. Details of location of traps at each site can be found in Appendix A, through to Appendix G.

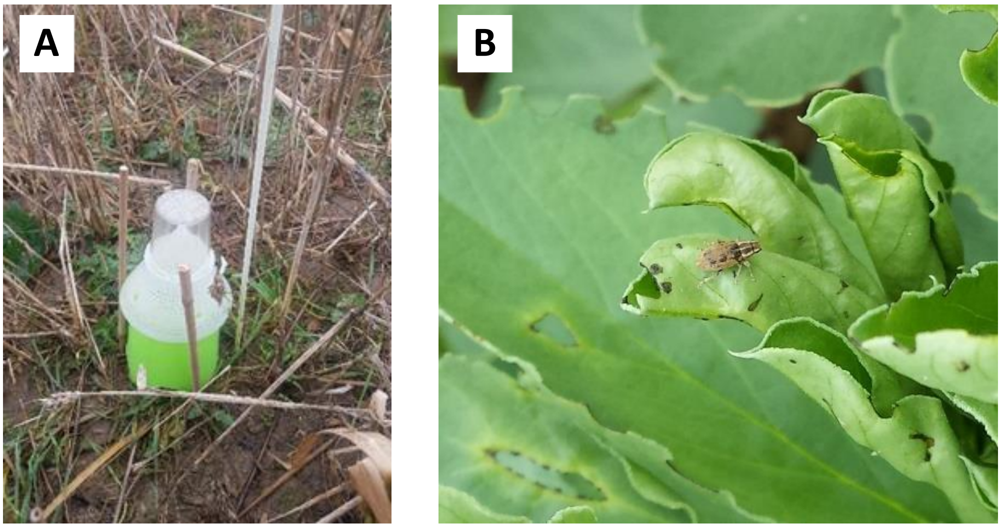

Figure 2. A) Pea and bean weevil pheromone baited station in situ. **B)** Pea and bean weevil adult feeding on foliage**.**

Bruchid beetle (*B. rufimanus*) plant volatile bait stations

B. rufimanus bait stations were placed within the trap crops and secured on canes at 1-metre height (Figure 3A). The bait stations were modified boll-weevil traps placed at height to allow beetles to enter the base of the station and crawl into the trap, where they were captured in a plastic bulb at the apex of the trap. Lures contained 1.32g of the active ingredients (-)-Linalool and (E)-Cinnamaldehyde at a ratio of 91:9, placed onto a wax plug. The baited plugs were secured to the inside of the green plastic cone. At each site, 40 stations were placed in the trap crops, arranged in two rows, approximately 10 metres apart. The traps were checked every two weeks and the number of beetles captured was recorded. Specific details of location of traps at each site can be found in Appendix A through to Appendix G.

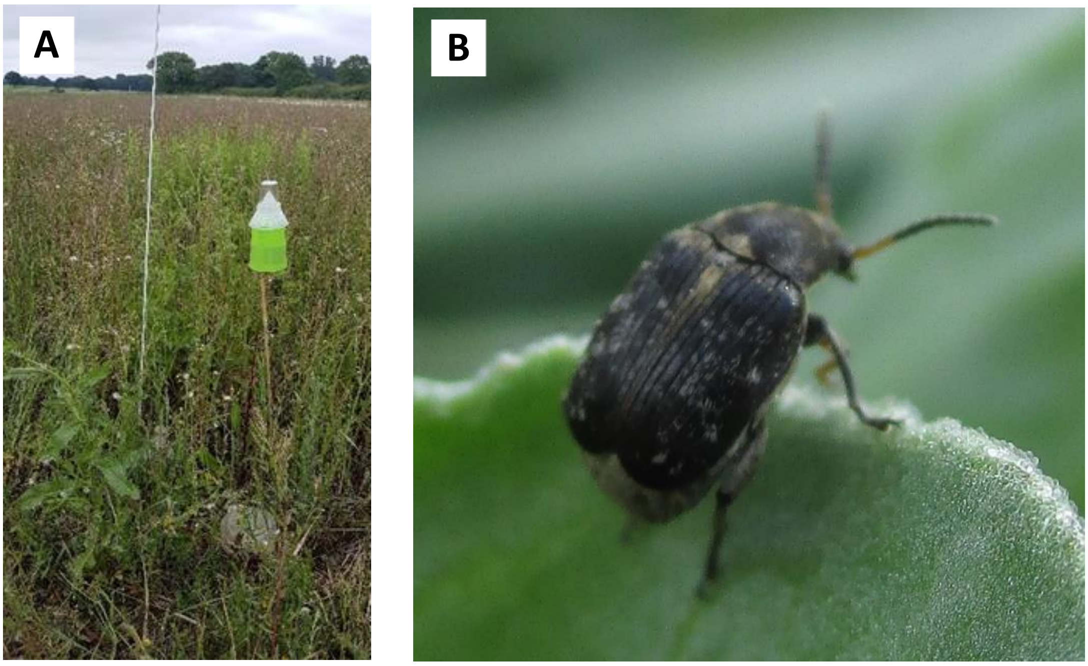

Figure 3. **A)** Bruchid beetle plant volatile baited station in situ. **B)** Bruchid beetle adult in field bean crop.

Pest damage and activity

Pea and bean weevil foliar damage assessment

Weevil assessments were conducted following EPPO guideline PP 1/60(3). Distinct adult weevil feeding notches were recorded on the top leaf pair on 20 plants at each sampling point in the main crop on at least two occasions following emergence of the crop (Figure 4).

Figure 4. Distinct adult pea and bean weevil leaf notching on field bean leaf edges.

Bruchid beetle seed damage assessment

At BBCH growth stage 97, harvest samples were taken at each site. 10 plants were collected from each sampling point within the main crop and trap crop at each site. Seeds from each plant were counted.

Seeds were cut open and examined for the presence of bruchid larvae or adults (EPPO guidance PP 1/175 (2)), or damage characterised by circular exit holes or circular clear 'windows' and brown markings on seed surfaces (Figure 5).

Figure 5. Bruchid adult emerging from seeds at maturity.

Aphid assessment

Aphid assessments were conducted in years where black bean aphids (*Aphis fabae*) were present. At each sampling point, aphids were recorded on 20 plants, and mean number of aphids, and aphid predator invertebrates per plant were calculated. Aphid predators largely included ladybirds and their larvae (Figure 6).

Figure 6. Ladybird larvae on aphid infested plant at ABB 23.

Biodiversity monitoring

Sweep netting

Sweep netting was carried out along two parallel transects 25 metres long, at least 25 metres apart and parallel to each trap crop using a long handled fine mesh net (Figure 7). The contents of each net were placed into a labelled plastic bag and sealed before being returned to the laboratory. Samples were frozen for a period, and then identified under a low powered microscope. Invertebrates were identified to species level where possible. Where not possible to identify individual species, individuals were identified to the lowest taxonomic group. Each site differed in the number of samples collected and location within the field, which are detailed in Appendix A to Appendix G.

Figure 7. Sweep netting invertebrate sampling.

Pitfall Traps

Pitfall traps with 250 ml capacity were placed at regular locations at each site in both the main crop and the trap crop. Each site differed in the number of samples collected and location within the field, which are detailed in Appendix A to Appendix G.

Pitfall traps were placed in the ground with the top of the trap level with the soil surface. A dilute antifreeze solution was used to prevent degradation of the samples, and a raised cover placed over the trap to prevent inundation with rainwater while allowing ground dwelling invertebrates to enter the traps (Figure 9). In 2021 the pitfall traps were collected every 2 weeks once *in situ*; however, this was changed due to the degradation of the samples after the 2 week period in the summer. In 2022 and 2023 samples were collected after 3 days. Samples were emptied into a resealable labelled bottle, returned to the laboratory, and refrigerated for a period until identification and recording of invertebrates took place. Invertebrates were identified to species level where possible. Where not possible to identify individual species, individuals were identified to the lowest taxonomic group.

Figure 8. Pitfall trap *in situ.*

Figure 9. Raised cover over pitfall trap to prevent rainfall inundation.

Data recording and analysis

Bruchid beetle damage was calculated as mean percentage seed damage at each sampling point by number of seeds. Pea and bean weevil damage was calculated as mean damage per plant (number of notches) at each sampling point. Aphid presence was calculated as mean number of aphids per plant.

An estimation of invertebrate diversity was calculated using the Simpson's diversity index for sweep netting and in pitfall traps at each site and between sites. Aphids and pea and bean weevil were removed from the pitfall and sweep net data to give an indication of non- "main pest" diversity.

Simpson's diversity index (D) was calculated using the formula:

$$D = 1 - \frac{\Sigma \mathrm{n}i(\mathrm{n}i - 1)}{\mathrm{N}(\mathrm{N} - 1)}$$

Where:

- n*i* = The number of organisms that belong to species *i*
- N = The total number of organisms

The value of Simpson's index ranges from 0 and 1, with a larger number indicating greater biodiversity.

Invertebrates were categorised at either 'pest' or 'non-pest' based on their ecological function and feeding behaviour, including species predated. For example, invertebrates which predate aphids were considered beneficial to managing aphid populations and thus categorised as non-pests.

When using the mixed system as a comparison to regenerative and conventional, it should be noted that only one field was used for this system, whereas the conventional and regenerative systems used five fields each across multiple years.

Statistical analyses were performed using R version 4.2.3 (R Core Team, 2023). For each field in each year, one-way ANOVAs were performed on percentage of bruchid damaged seeds, number of weevil notches, and number of aphids at each sampled distance and within the trap crops or at 0 metres. A post-hoc least significant difference (LSD) test was performed on fields with a statistically significant ANOVA result.

Linear regression analysis was performed in the assessment of yield and aphid numbers, and yield and distance.

Yield

At BBCH growth stage 97, harvest samples were taken at each site. Ten plants were collected from each of the assessment/ sampling points within the main crop. Pods were removed from the plants and seeds removed from pods and weighed. Yield was calculated as tonnes per hectare for each sampling point, taking into account the plant density counts carried out at early crop growth stages.

Results

Weevil

The effect of pheromone lures on weevil populations

Results regarding the effectiveness of pea and bean weevil pheromones for attracting weevils to the trap crop were mixed, with varying results across different sites. At HH 21, comparable fields 9 and 10, each containing no lures and lures respectively, showed mean number of weevil notches in the field with lures was significantly higher than the field without ($p < 0.001$) (Figure 10). At WW 22, when adjacent fields 1 (lures), 2 (no lures), and 3 (no lures) were assessed, results showed no significant difference between mean weevil notches in fields with or without lures (Figure 11).

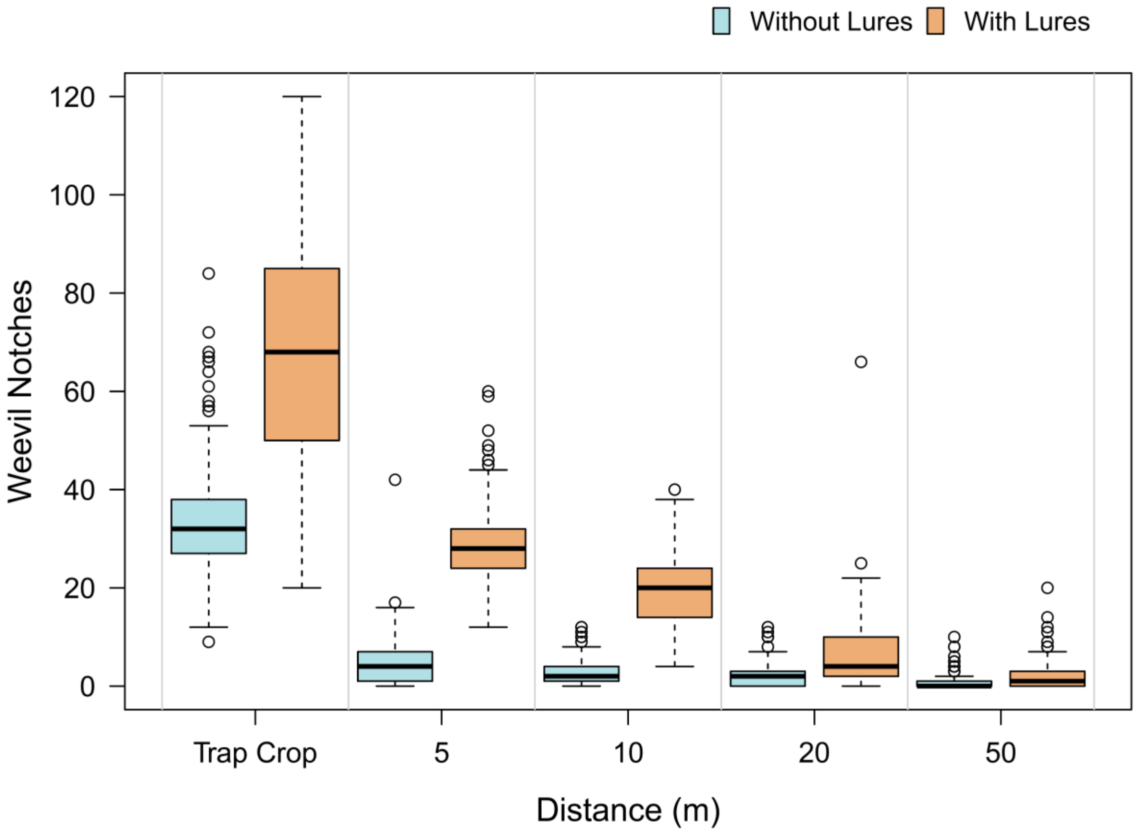

Figure 10. Weevil notches per plant at varying distances from a trap crop containing lures compared to a trap crop without lures, HH 21.

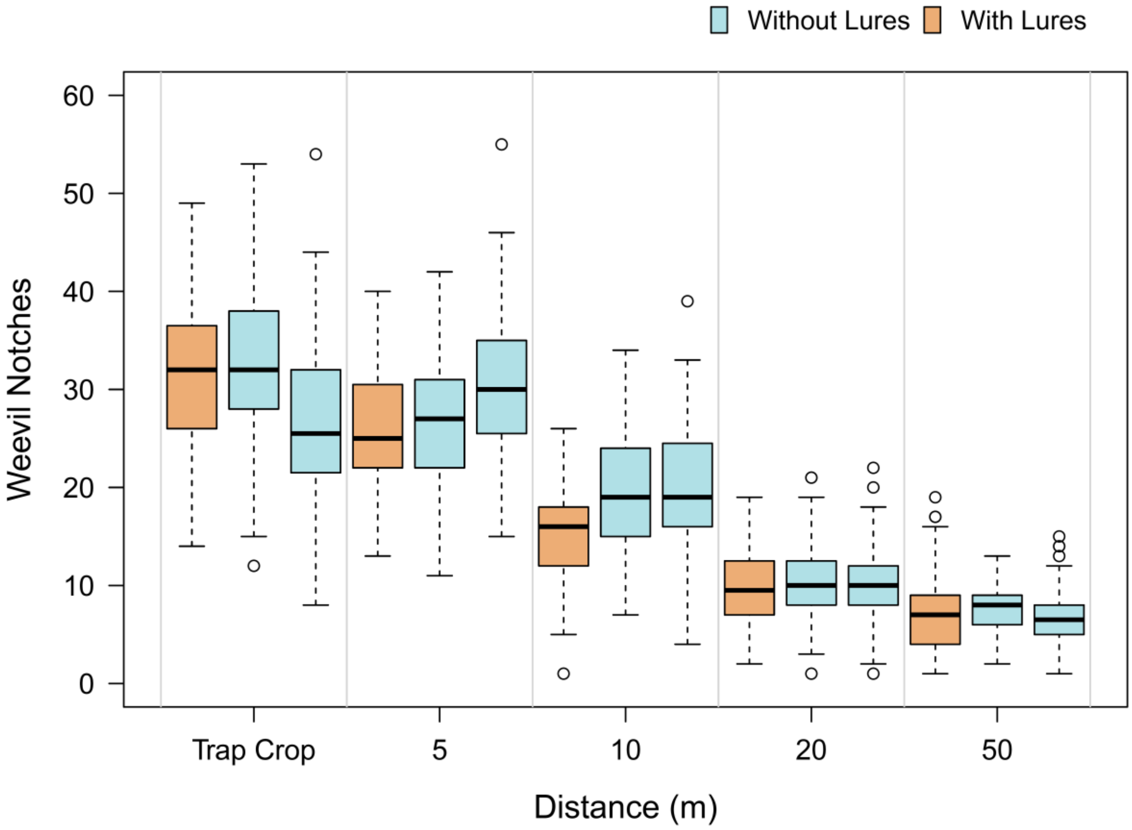

Figure 11. Weevil notches per plant at varying distances from a trap crop containing lures compared to two trap crops without lures, WW 22 (Fields 1, 2 and 3).

The effect of trap crops on weevil damage

At HH 21, both fields showed weevil damage that was significantly higher in the trap crop than any other sampled distance within the main crop, on both April and May sampling dates ($p < 0.05$) (Figure 12; Figure 13).

At WW 22, damage was generally highest within the trap crops and field edges in April, decreasing further with distance into each field (Figure 14 and Figure 15). On the May sampling date, weevil numbers in the Field 1 trap crop and at 10m were significantly higher than at the other distances sampled. In Field 3, weevil numbers were highest at 10m, and the difference was statistically significant. The data appears to show a migration of weevils further into the main crop over time, with highest levels of damage gradually shifting over time.

In WW 22 Field 4, the control field, weevil numbers were significantly higher at 0m in both sample months, without the presence of a trap crop. The similar pattern of weevil damage between fields with trap crops and the control crop may indicate the trap crops gave little benefit over natural spatial distribution of weevil populations in terms of reducing weevil damage to the main crop. In May, weevil damage throughout the main crop was at a lower level in the control crop than the trap crops.

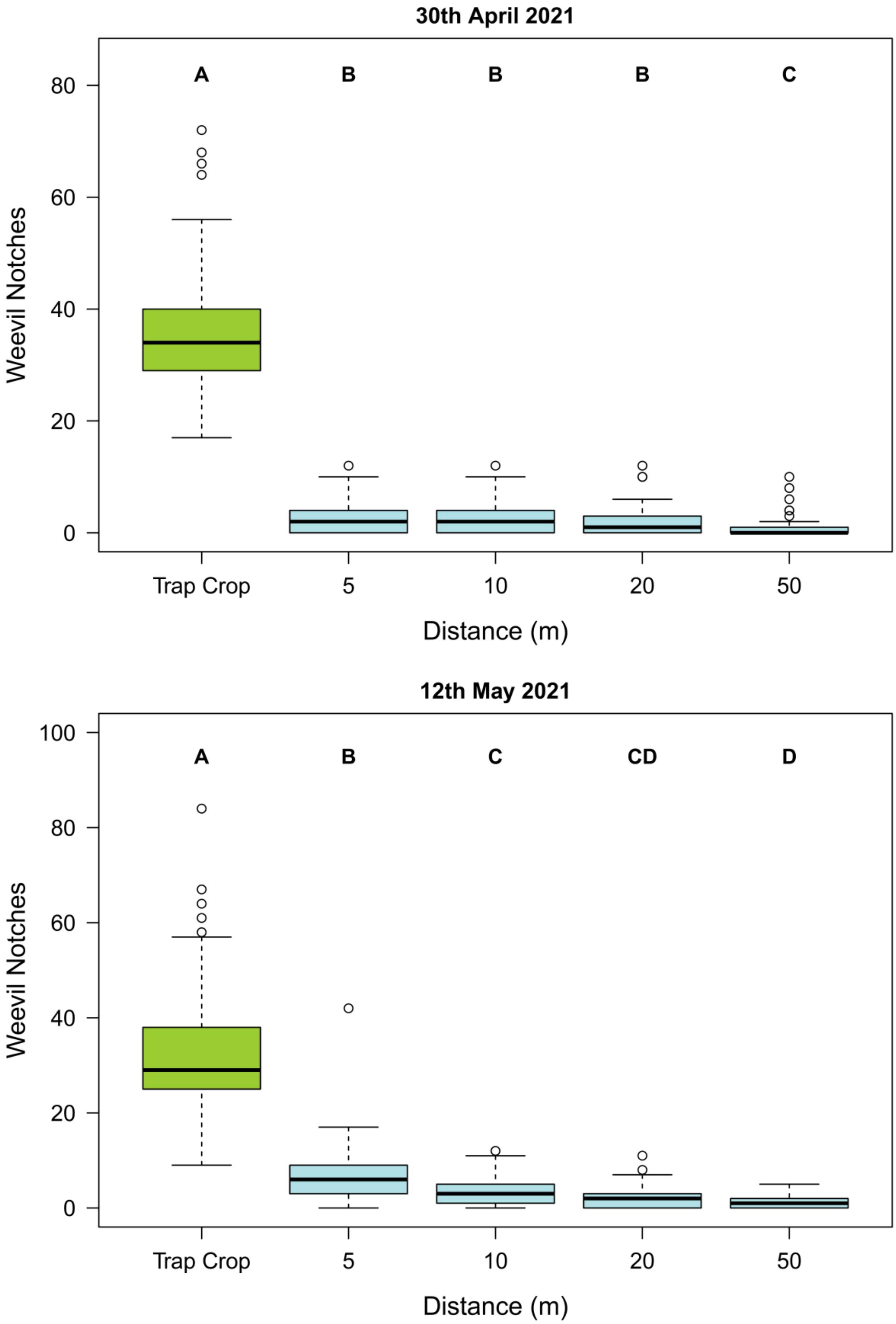

Figure 12. Weevil notches per plant at varying distances from the early-sown bean trap crop, in Field 9, HH21, across two sampling dates.

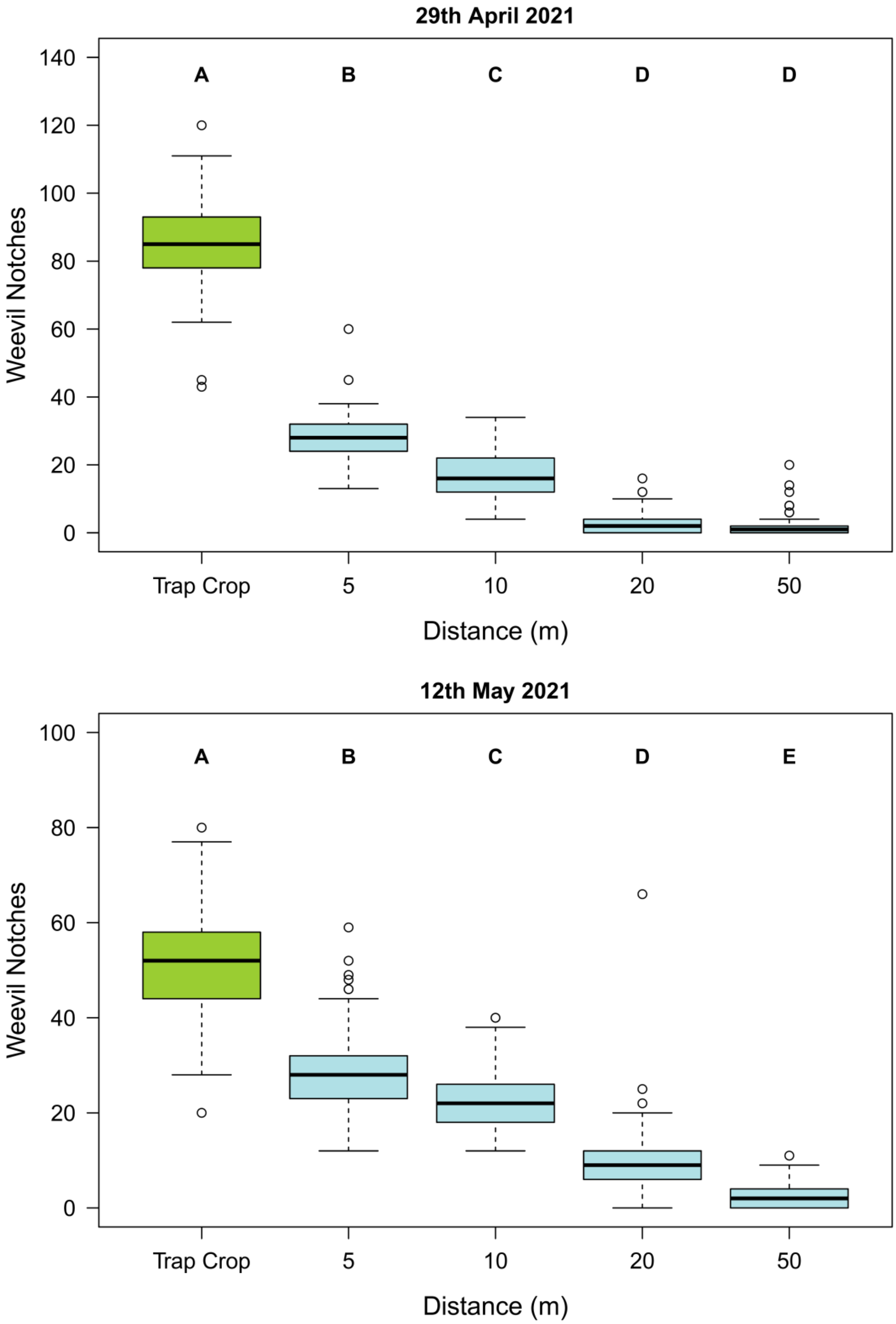

Figure 13. Weevil notches per plant at varying distances from the early-sown bean trap crop, in Field 10, HH21, across two sampling dates.

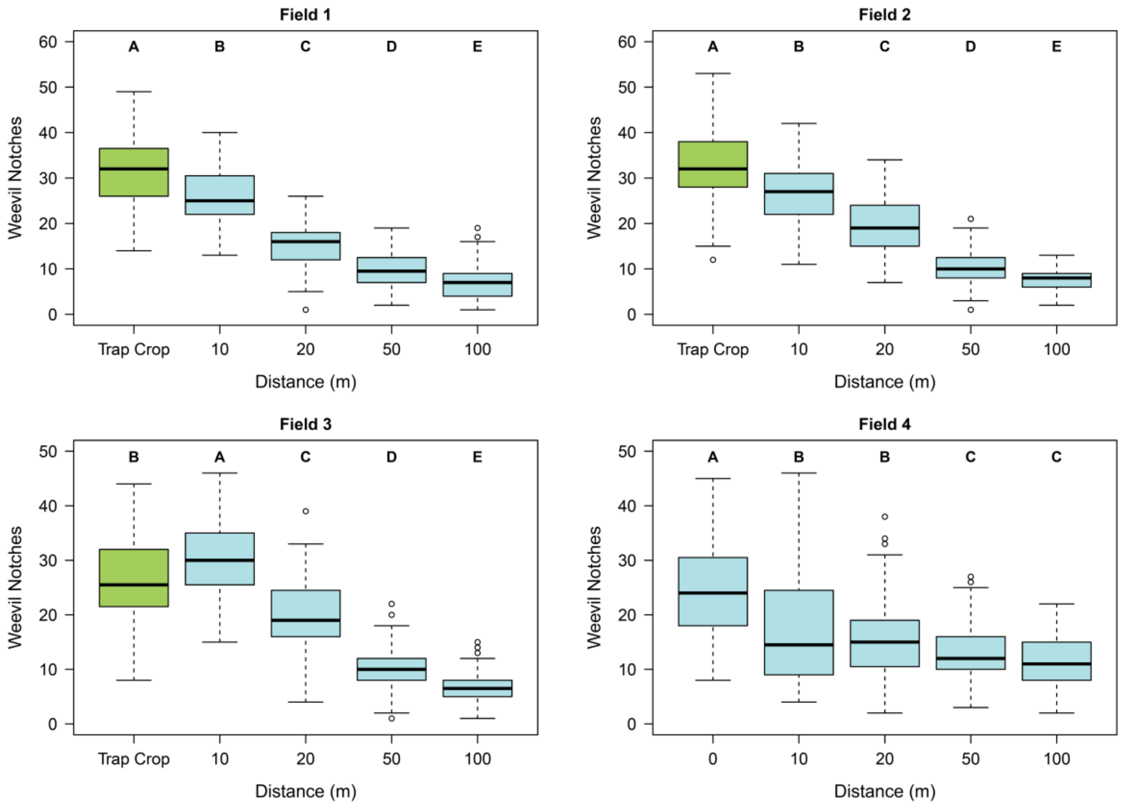

Figure 14. Weevil notches per plant at varying distances from the trap crop (Fields 1, 2 and 3) or field edge (Field 4), WW 22, April 2022.

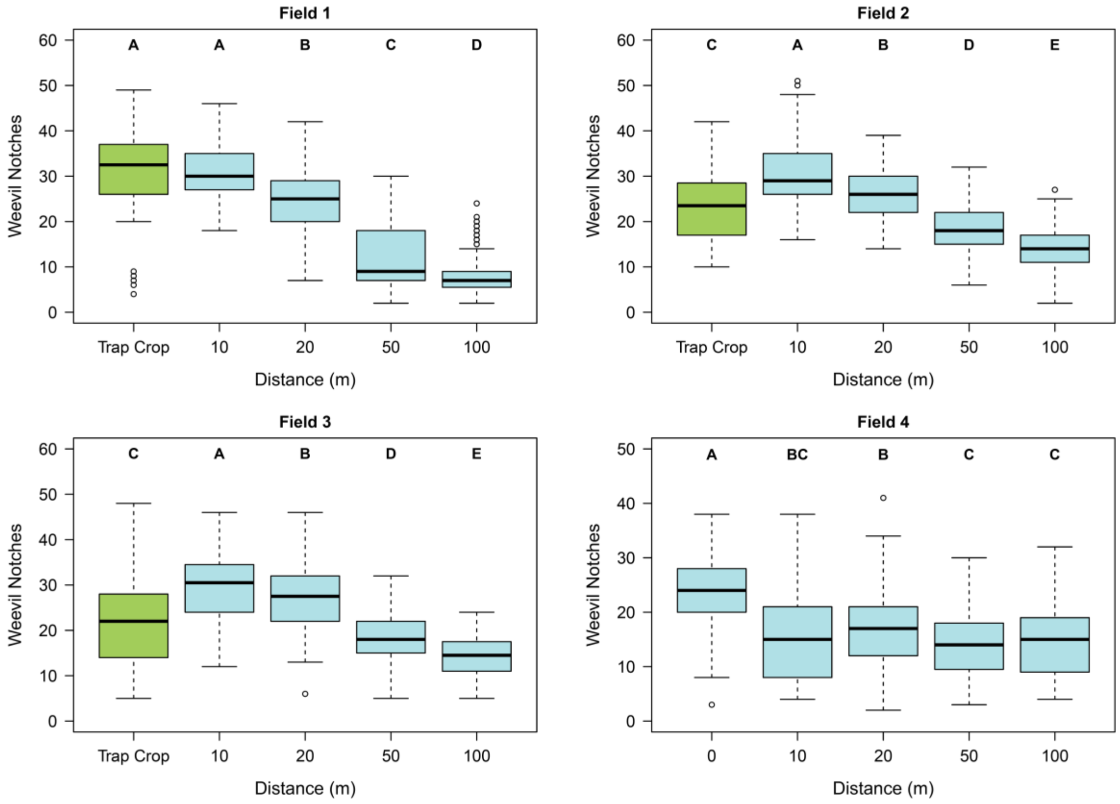

Figure 15. Weevil notches per plant at varying distances from the trap crop (Fields 1, 2 and 3) or field edge (Field 4), WW 22, May 2022.

Weevil notch assessments at ABB 23 on 4th May 2023 indicated significantly higher levels of weevil damage closer to the field margins ($p < 0.05$) (Figure 16). There was no difference in levels of damage at either end of the field, suggesting the legume-rich flower margin and tussocky grass margin may have performed a similar function. There were significantly lower levels of weevil damage in the centre of the field at 100m and 150m.

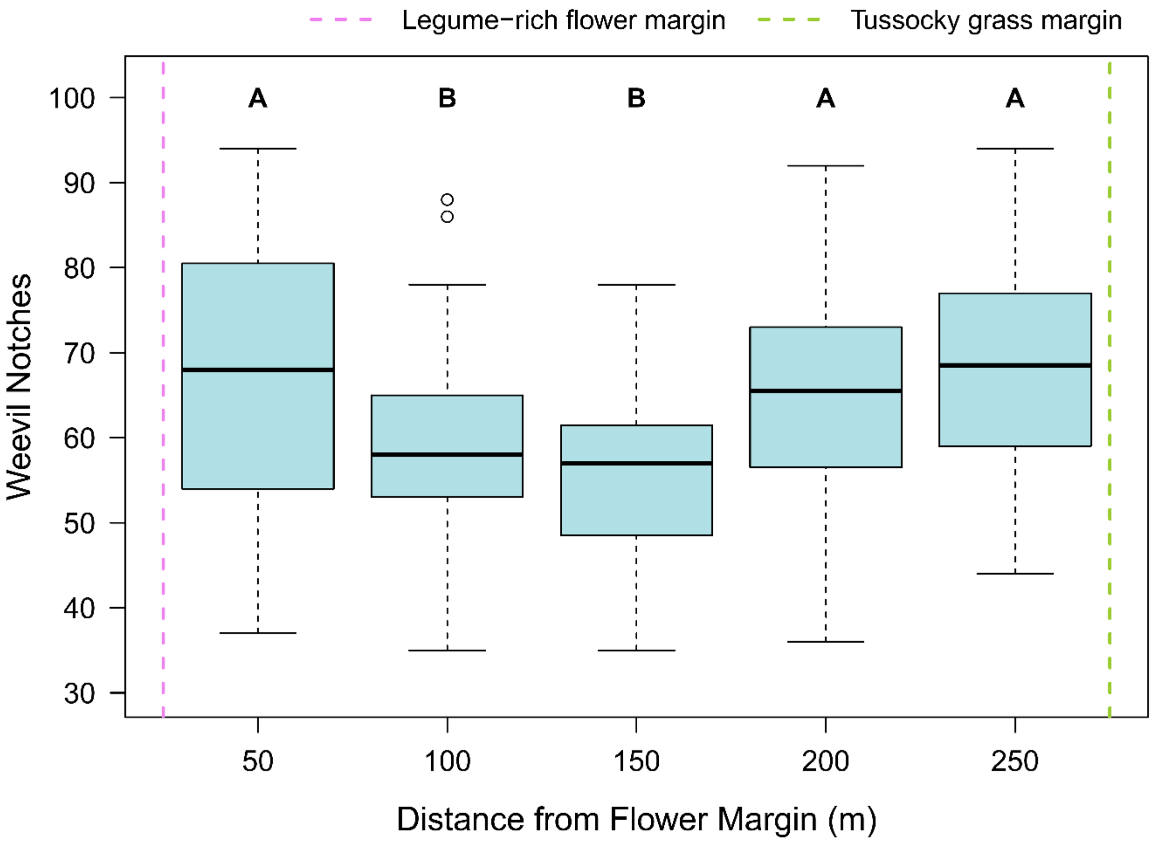

Figure 16. Weevil notches per plant at varying distances from the legume-rich flower margin at ABB 23. Letters indicate statistically significant differences between means. Dashed lines indicate the locations of perennial flowering and grass margins.

Weevil damage in the conventional farming system at ALC 23 was comparatively lower than in the regenerative system at ABB 23. On the 17th April, weevil notches observed in the early-sown trap crop were significantly higher than in the main crop (Figure 17). When measured again on 3rd May, weevil damage was higher at all distances, and although ANOVA results showed weevil damage to be significantly different between distances ($p < 0.001$), LSD analysis showed the trap crop was only significantly different from the mean at 100m (Figure 17).

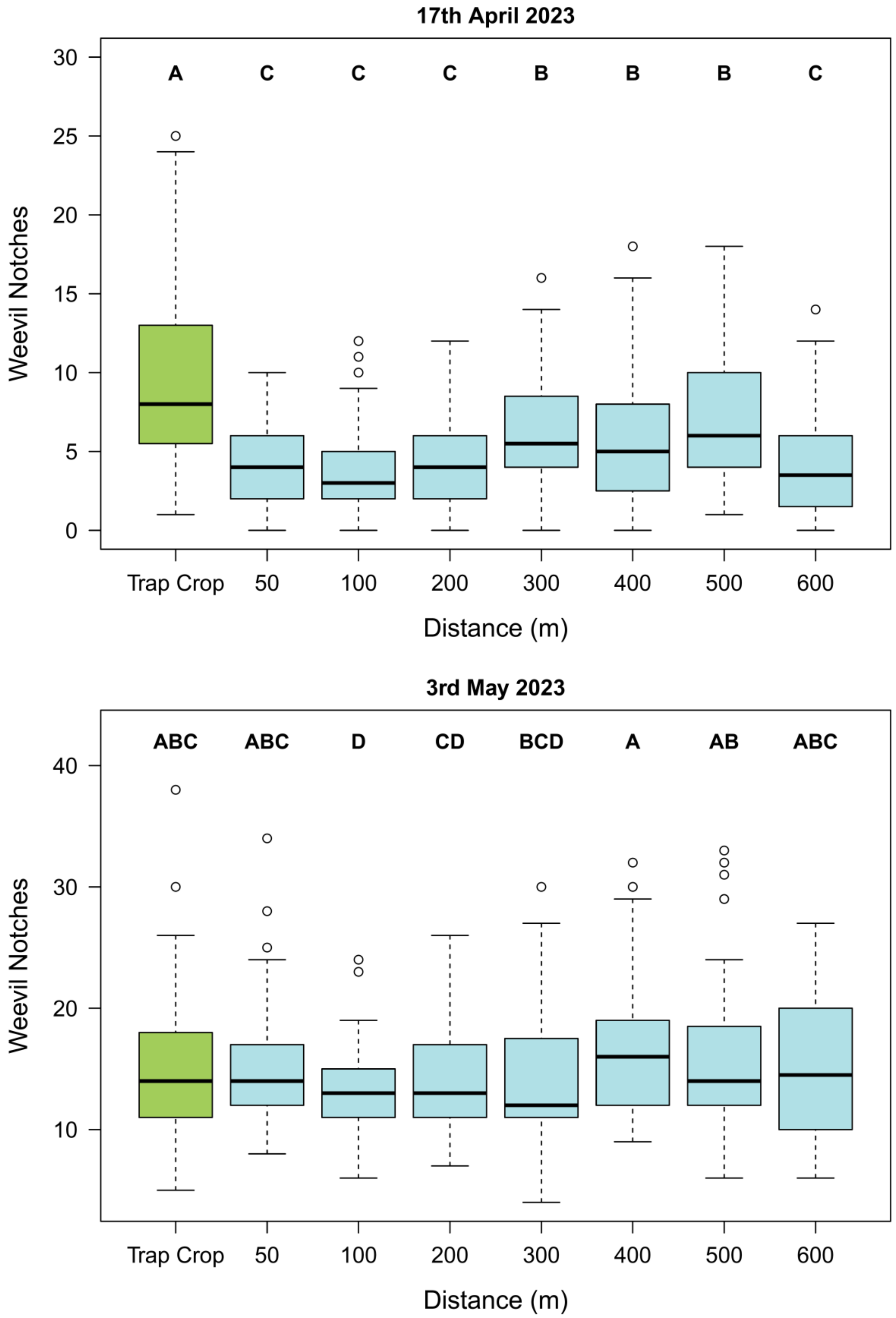

Figure 17. Weevil notches per plant with distance from the trap crop at ALC 23. Letters indicate statistically significant differences between means.

The impact of farming systems on weevil damage

There was overall no significant difference in weevil notches between conventional or regenerative farming systems. Damage to the control crop in the conventional system however was significantly lower than the field containing the trap crop and both regenerative crop types (p < 0.05) (Figure 18).

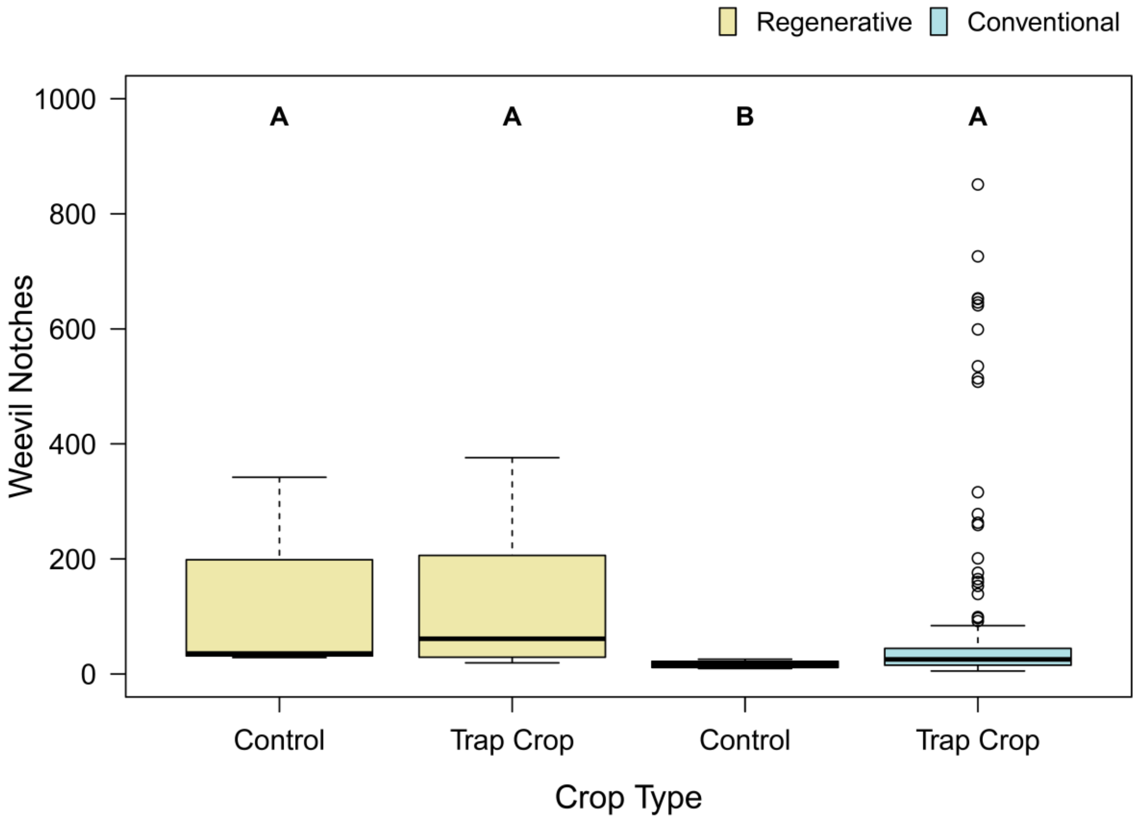

Figure 18. Weevil notches per plant in control and field containing trap crops, in regenerative and conventional farming systems. Letters indicate statistically significant differences between means.

Bruchid

The effect of plant volatile bait stations on bruchid populations

The presence of plant volatile bait stations did not appear to have an impact on the presence of bruchid beetles within the trap crops or main crops, with no significant difference found between comparable lure and non-lure fields at HH 21 (*p* = 0.883) (Figure 19), or at WW 22 (*p* = 0.056) (Figure 20).

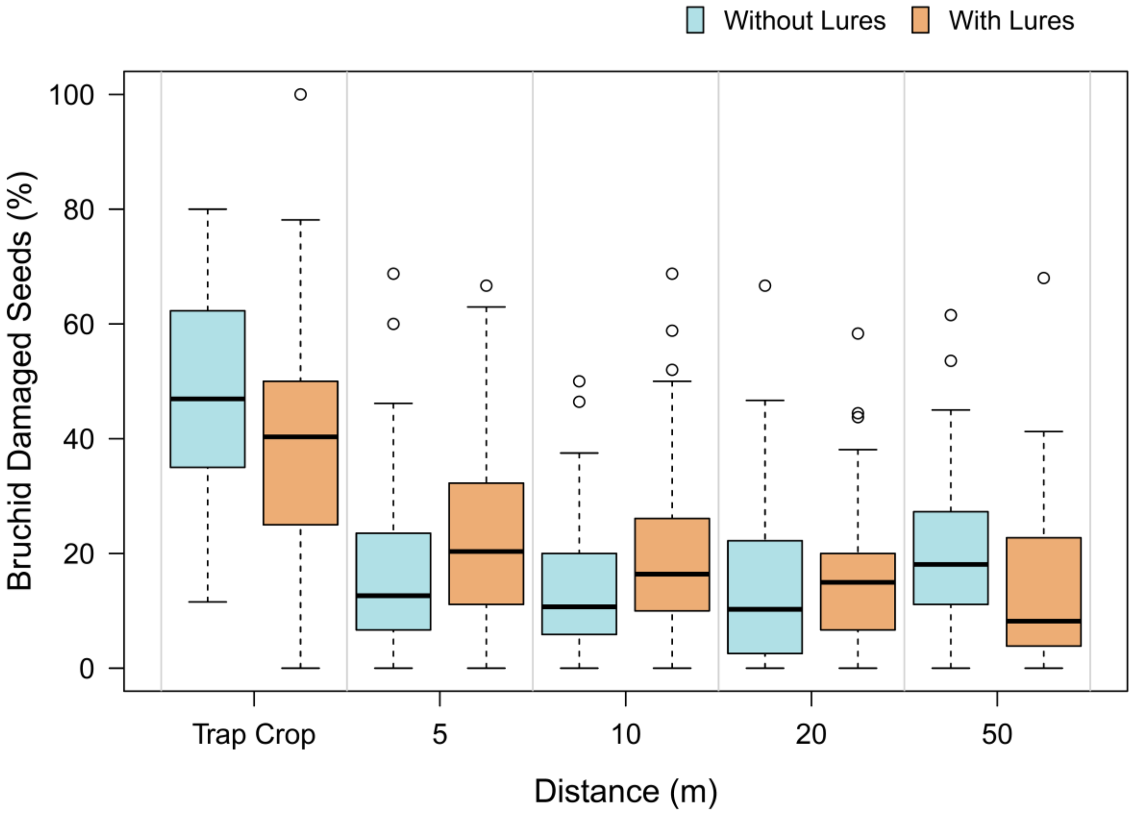

Figure 19. Percentage of bruchid damaged seeds at varying distances in a trap crop containing lures compared to a trap crop without lures, HH 21 (Fields 9 and 10).

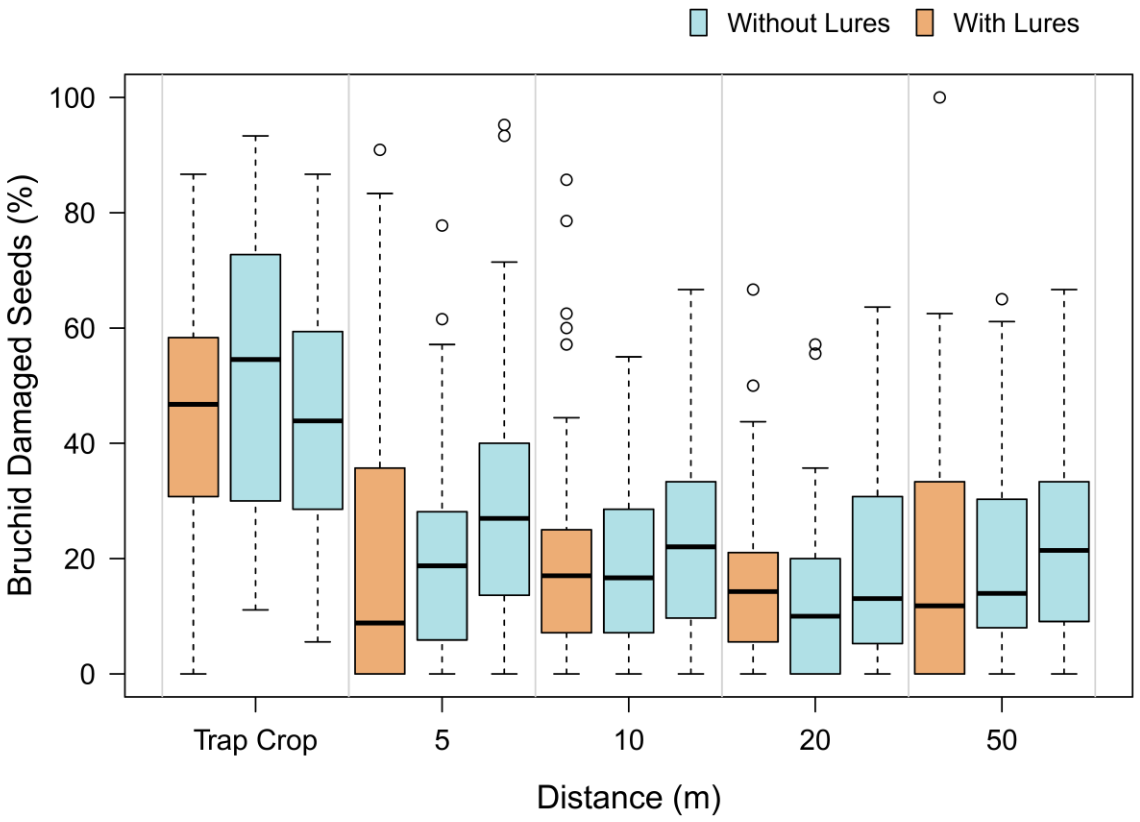

Figure 20. Percentage of bruchid damaged seeds at varying distances in a trap crop containing lures compared to two trap crops without lures, WW 22 (Fields 1, 2 and 3).

The effect of trap crops on bruchid beetle damage

All three trap crop fields (Fields 1 to 3) at WW 22 showed bruchid damage that was significantly higher in the trap crop than in the main crop ($p < 0.05$) (Figure 21). A significantly higher percentage of bruchid damage was also observed at 0m in Field 4 ($p < 0.05$), which was a control crop with no trap crop, compared to the rest of the field. Median percentage bruchid damage was slightly lower at 0m in the control crop than in the trap crops.

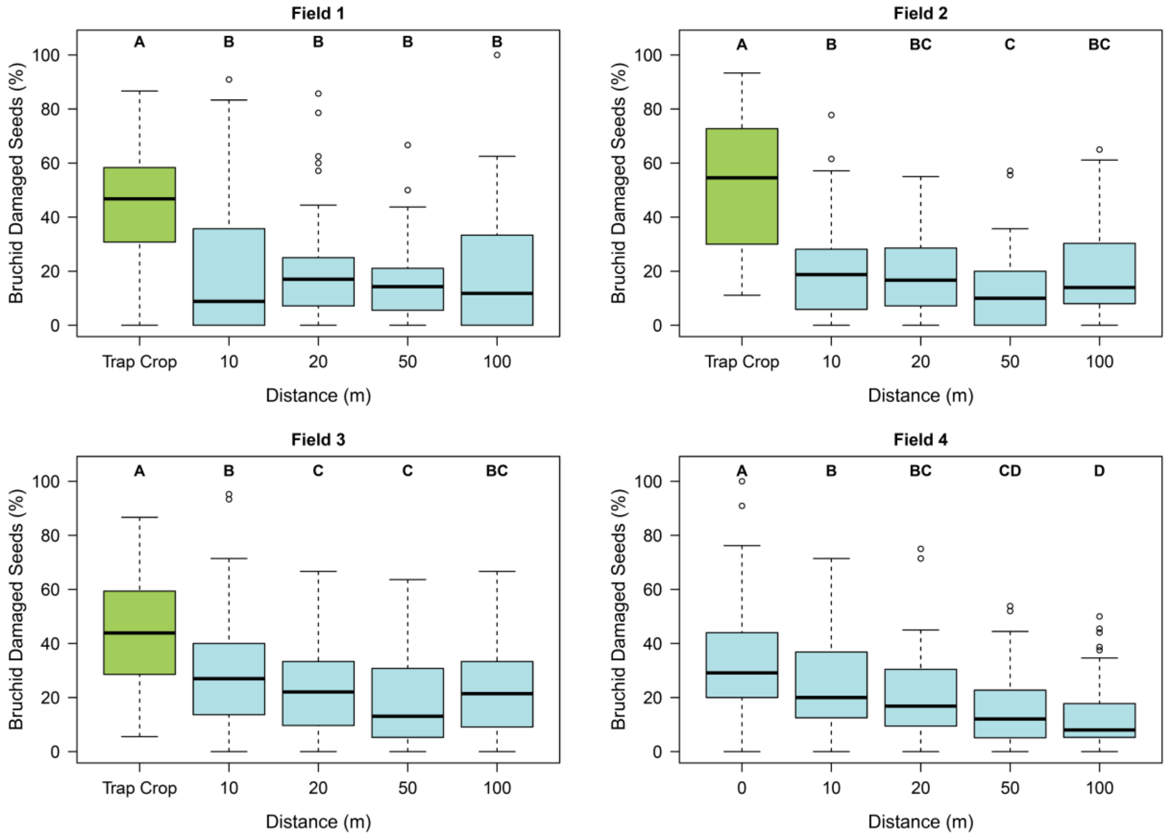

Figure 21. Percentage bruchid damaged seeds with distance from the trap crop (Fields 1 to 3) or field edge (Field 4). Letters indicate statistically significant differences between means.

A similar trend to that found in weevils was observed for bruchid at ABB 23, with instances of higher bruchid damage closer to the legume-rich flower and tussocky grass field margins (Figure 22). Mean percentage damage between the distances was not significantly different however (p = 0.163).

Mean bruchid damage in the trap crop in ALC 23 was significantly higher than at all other distances except 200m ($p < 0.05$) (Figure 23). The data indicates a decline in bruchid damage across the full 600m cross section of the field.

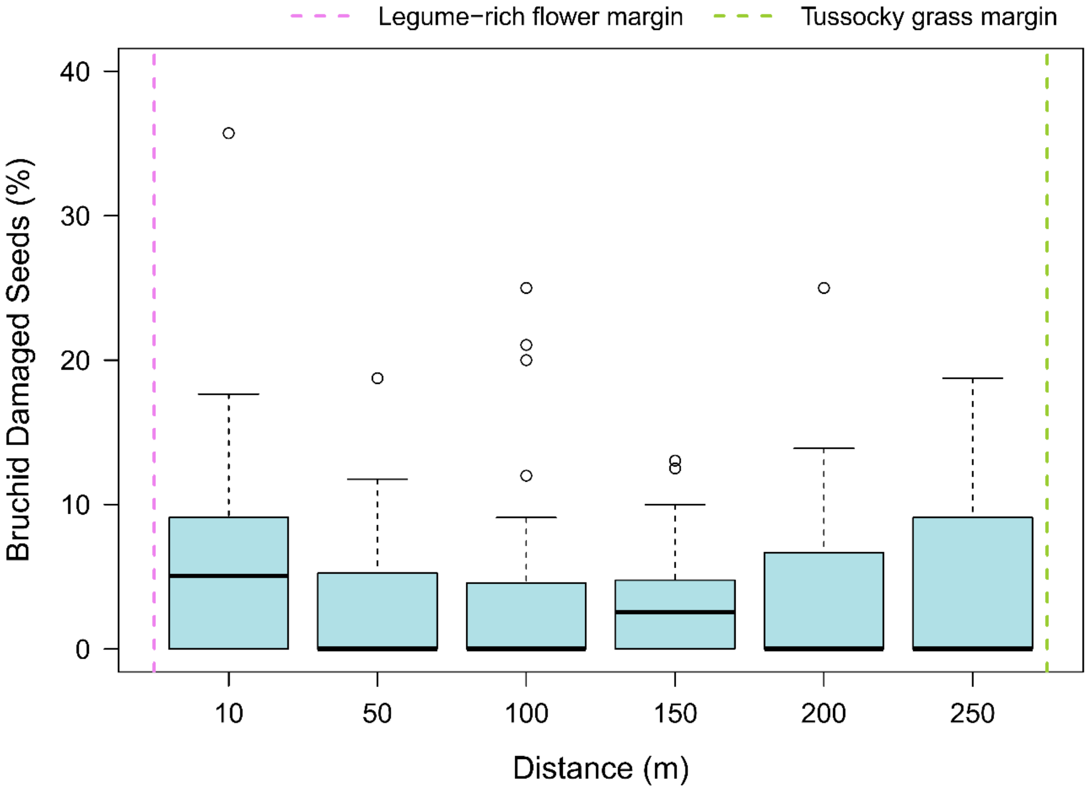

Figure 22. Percentage bruchid damaged seeds with distance from the legume-rich flower margin at ABB 23. Dashed lines indicate the locations of perennial flowering and grass margins.

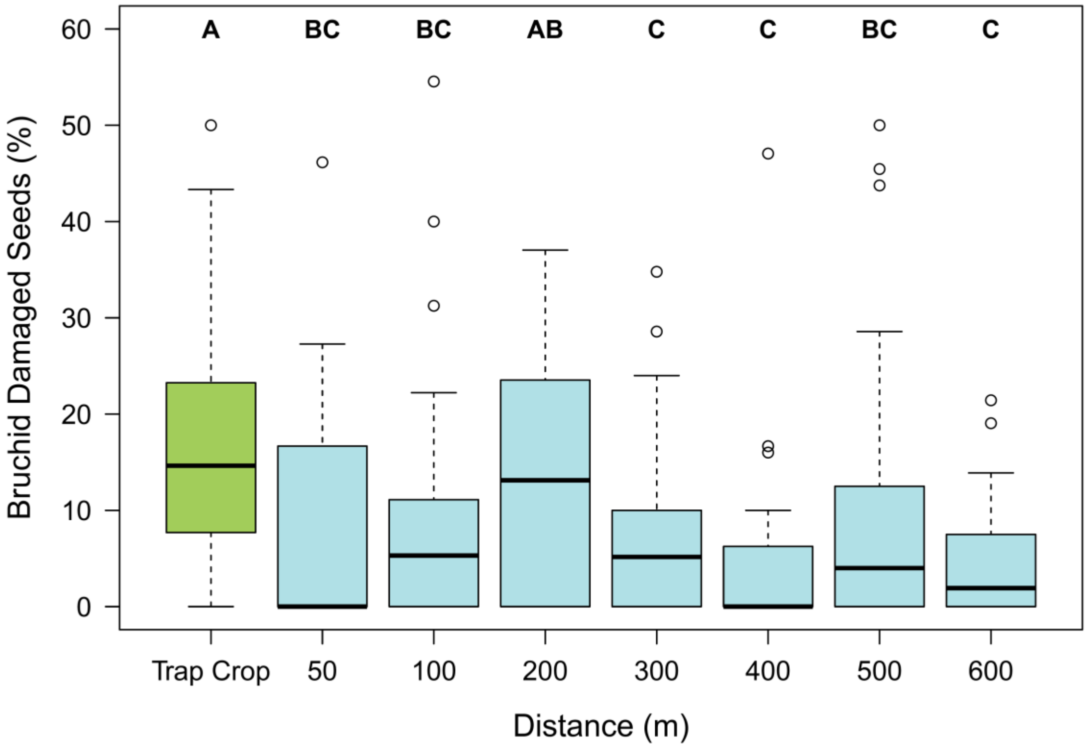

Figure 23. Percentage bruchid damaged seeds with distance from the trap crop, ALC 23. Letters indicate statistically significant differences between means.

The impact of farming systems on bruchid damage

Bruchid damage was lower in the trap crop than the control for both conventional and regenerative farming systems (Figure 24). In the regenerative system, the difference was not significant, however in the conventional system bruchid damage in the field containing the trap crop was significantly lower than the control crop ($p < 0.05$). There was a highly significant difference in mean bruchid damage between the regenerative and conventional farm types ($p < 0.001$), with mean bruchid damage lower in the regenerative systems.

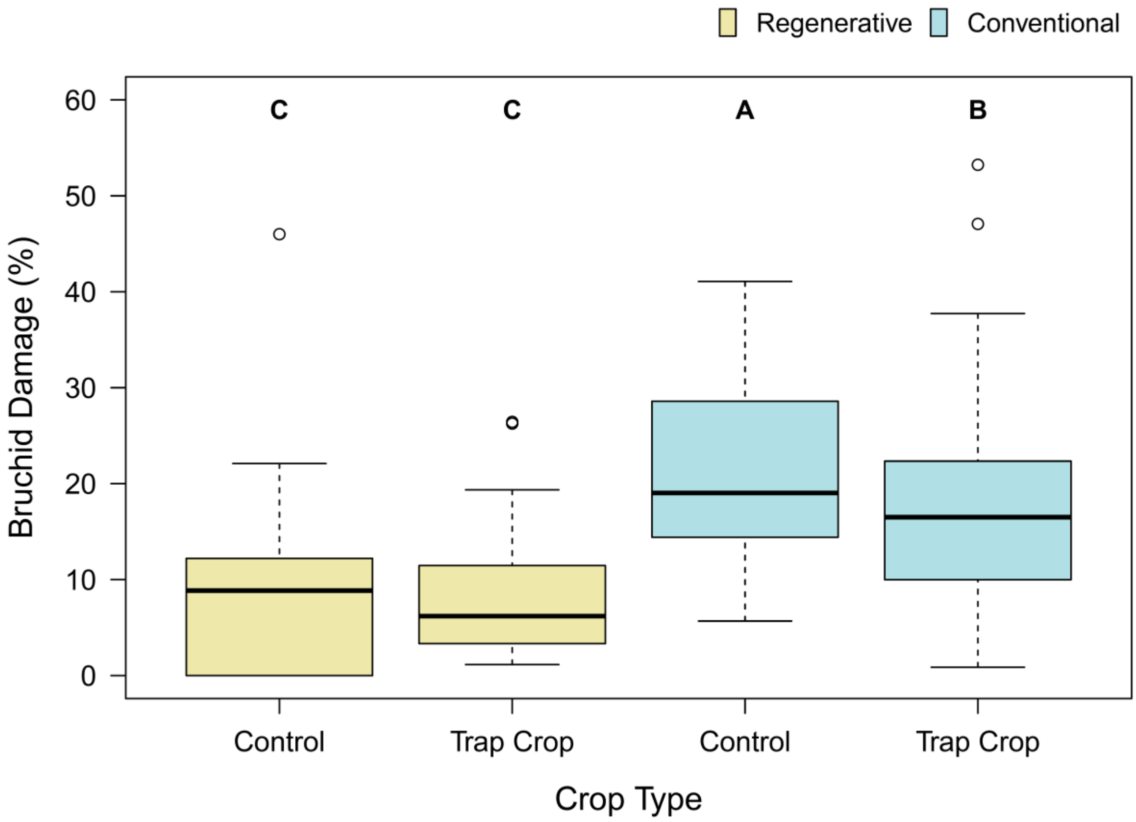

Figure 24. Percentage bruchid damaged seeds in control crops and field containing the trap crops, in regenerative and conventional farming systems. Letters indicate statistically significant differences between means.

Aphids

The effect of trap crops on aphid populations

Unlike weevil and bruchid damage at WW 22, aphid numbers were highly variable between fields (Figure 25). In Field 1, aphid numbers were low overall. In Fields 1 to 3, aphids were low or not present in the trap crop, but much higher at 0m in the control crop (Field 4). In Fields 1 to 3, aphid numbers generally increased with distance from the trap crop.

Aphid numbers were significantly higher closer to the trap crop and perennial flowering margin at PAP 22 (Figure 26). Both crops showed the same distribution of aphids, with lower numbers observed further away from the field margins and into the centre of the larger crop area (Appendix figure 7).

The association between aphid numbers and harvested yield was assessed. There is a clear and significant negative association between aphid numbers and yield ($p < 0.05$) (Figure 27), with yield significantly declining with increasing aphid numbers, and the linear model indicating a decrease in yield of 0.48t/ha with every additional 100 aphids per plant.

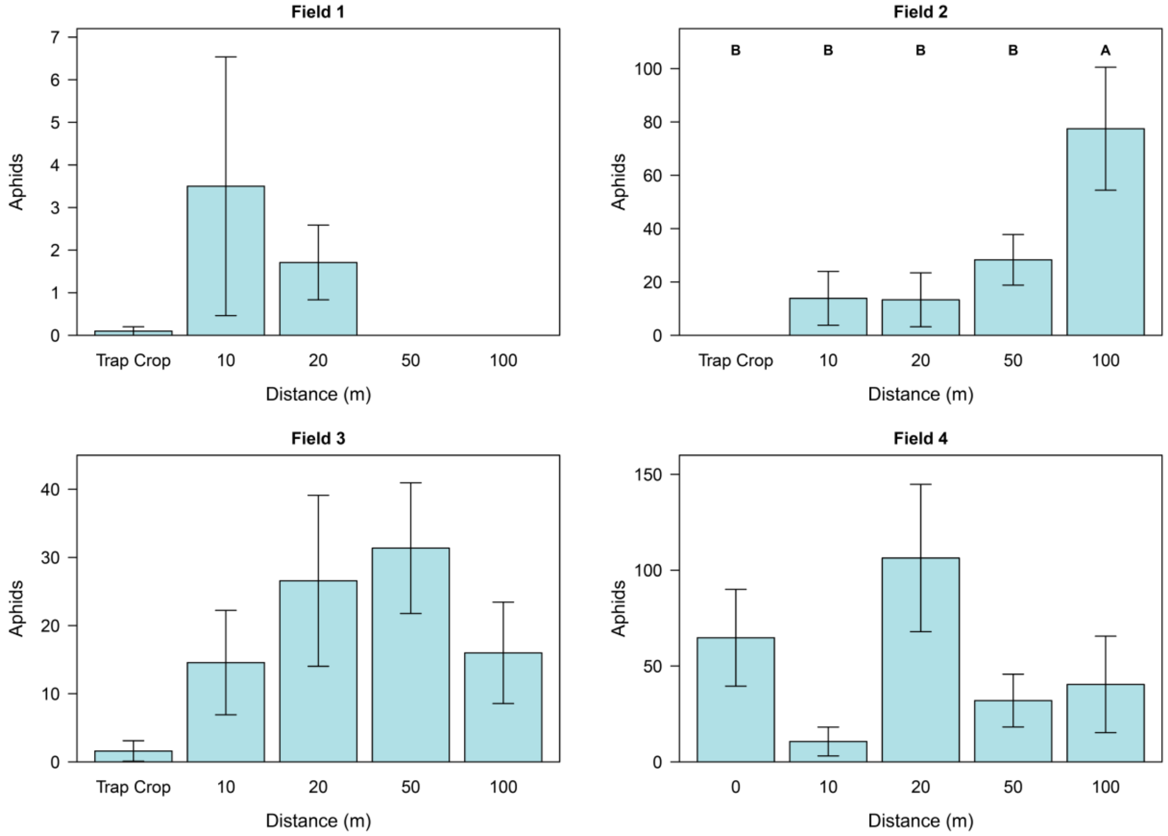

Figure 25. Mean number of black bean aphids per plant at varying distances from the trap crop (Fields 1, 2 and 3) or field edge (Field 4), WW 22, April 2022. Standard error bars are shown. Letters indicate statistically significant differences.

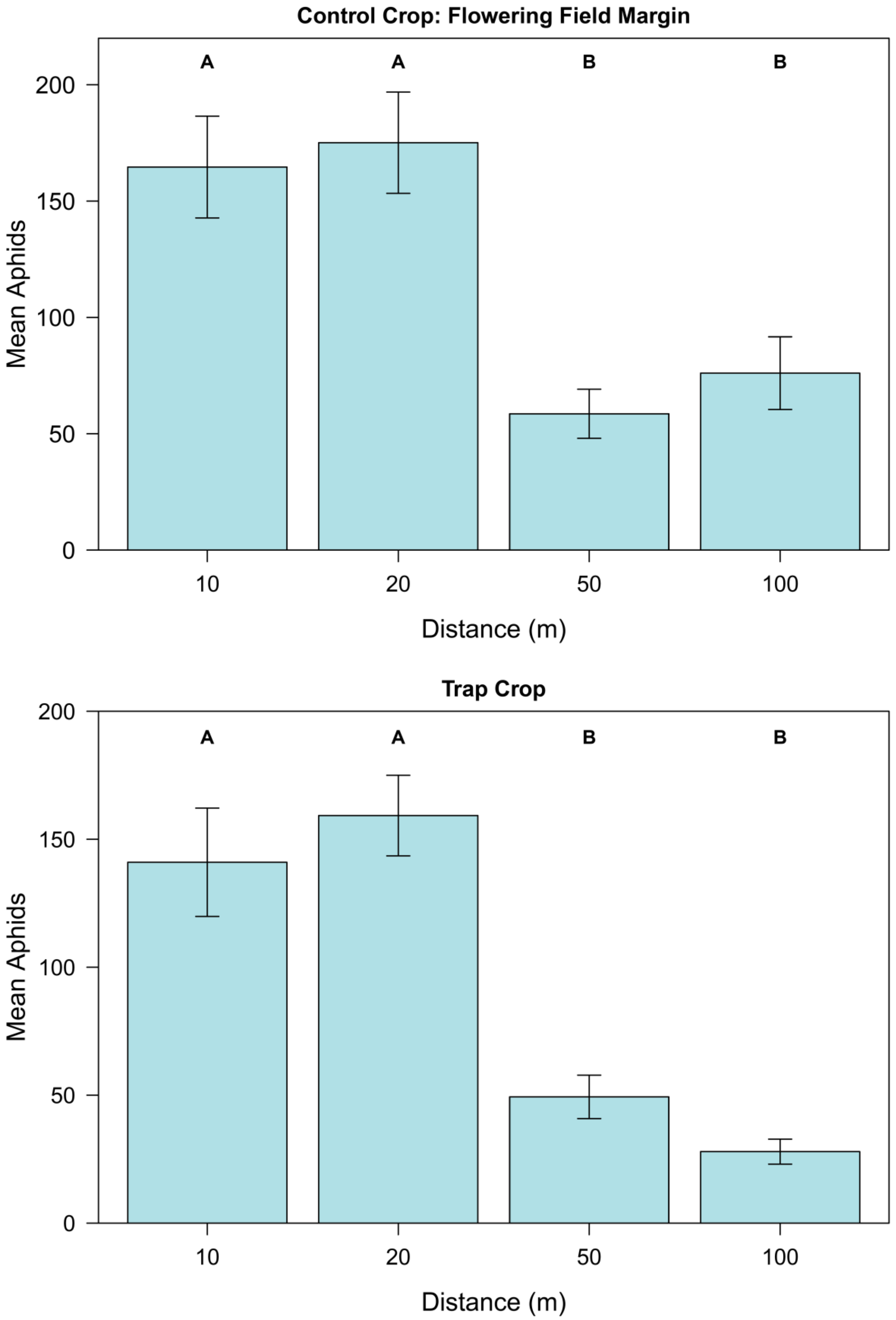

Figure 26. Mean number of aphids per plant in control crop with a perennial flowering field margin (upper panel), and legume-rich flowering trap crop (lower panel).

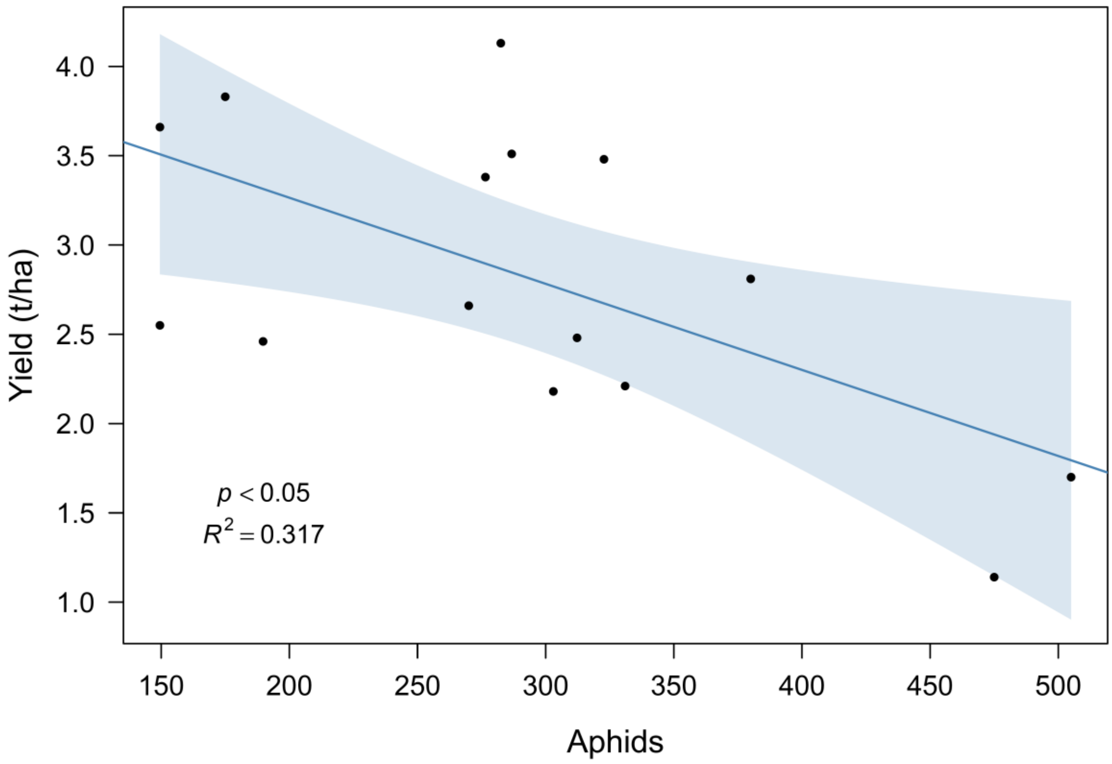

Figure 27. Relationship between yield and number of aphids at ABB 23. Shaded band indicates 95% confidence interval.

The impact of farming systems on aphid populations

Aphid numbers were significantly higher in the regenerative farms than conventional ($p < 0.001$), but there was no significant difference between the control crops and fields containing trap crops in the regenerative system (Figure 28). Within the conventional system aphid numbers in the trap crop were significantly lower than the control ($p < 0.05$).

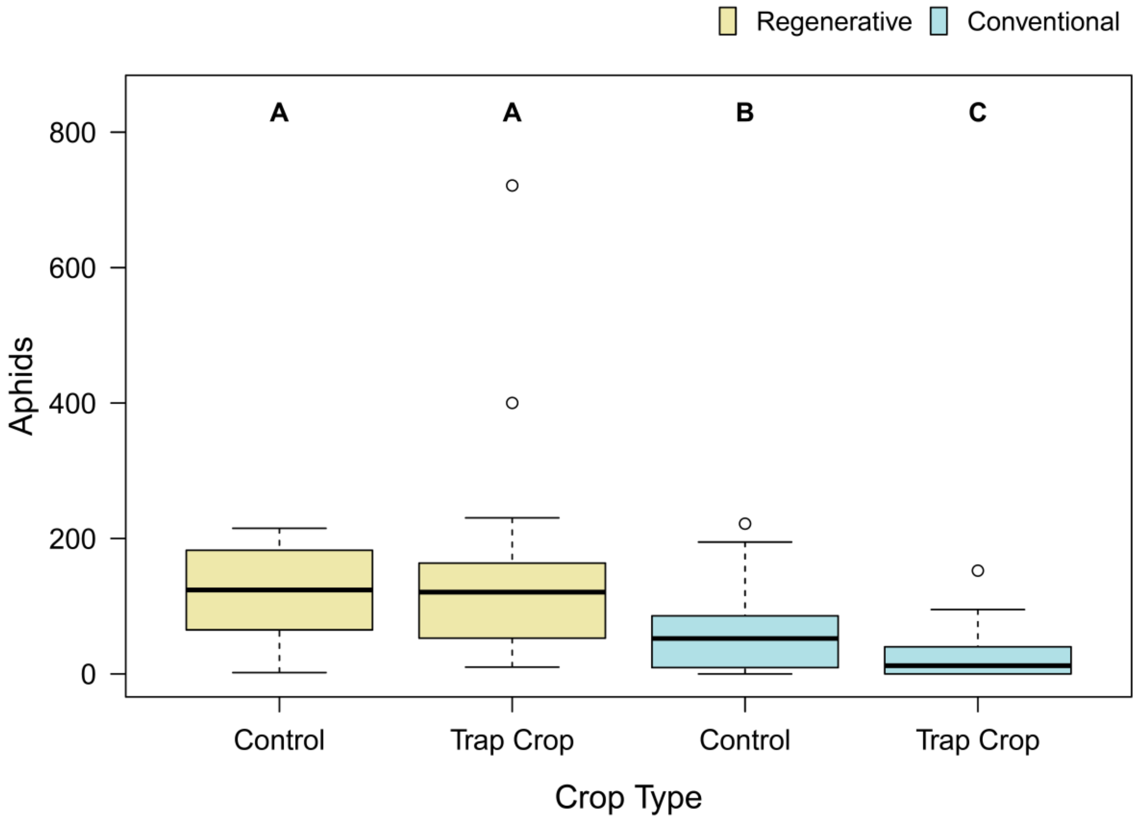

Figure 28. Aphids in control crops and fields containing trap crops, in regenerative and conventional farming systems. Letters indicate statistically significant differences between means.

Biodiversity

In pitfall traps, ground beetles, common sun beetles, and spiders were sampled in the greatest numbers (Table 2), whilst in sweep netting, large flies, pollen beetles and parasitic wasps were sampled in the greatest numbers (Table 3).

There was a significant difference in Simpson's diversity index between pitfall trap samples from each of the conventional, mixed, and regenerative farming systems ($p < 0.001$). The mixed farm had a significantly lower mean diversity index than conventional or regenerative farming systems ($p < 0.05$), with an index of 0.468 compared to 0.615 and 0.644, respectively.

There was a significantly higher mean percentage of pests, and significantly fewer non-pest invertebrates in the conventional farming system than the mixed or regenerative systems ($p < 0.05$) (Figure 29). Regenerative farming systems showed the lowest percentage of pests, but the mean was not significantly lower than the mixed system.

For the sweep net data, there was a significant difference in Simpson's diversity index between the systems ($p < 0.01$). The regenerative farming systems had a significantly higher mean diversity index than the mixed or conventional farms ($p < 0.05$), with a mean index of 0.674, compared to 0.457 and 0.584, respectively. Percentage of pest species was highest in the conventional farming system, however, there was no significant difference between percentages of pest or non-pest invertebrate species between the farm types ($p = 0.208$) (Figure 30).

Overall, regenerative farms had a greater proportion of non-pest species compared to conventional farms, and in sweep netting data, this was associated with a higher Simpson's diversity index. In pitfall trap data, the Simson's diversity index of regenerative and conventional farms was not significantly different. Diversity indices were lowest in the mixed farming system for both pitfall trap and sweep net data.

Table 2. Invertebrates sampled in pitfall traps across all years.

Common Name	Taxonomy	Classification	Total Number Observed
Common Sun Beetle	sp. *Amara aenea*	Non-pest	1653
Ground Beetle	Family Carabidae	Non-pest	10803
Rove Beetle	Family Staphylinidae	Non-pest	164
Ladybird	Family Coccinellidae	Non-pest	74
Beetle (other)	Order Coleoptera	Non-pest	637
Springtail	Subclass Collembola	Non-pest	29
Spider	Order Araneae	Non-pest	1555
Harvestman	Order Opiliones	Non-pest	174
Centipede	Class Chilopoda	Non-pest	47
Earwig	Order Dermaptera	Non-pest	11
Bee	Superfamily Apoidea	Non-pest	13
Hoverfly	Family Syrphidae	Non-pest	1
Parasitic Wasp	Suborder Apocrita	Non-pest	100
Woodlouse	Suborder Oniscidea	Non-pest	904
Cricket	Superfamily Grylloidea	Non-pest	1
Black Ant	sp. *Lasius niger*	Non-pest	83
Red Wood Ant	sp. *Formica rufa*	Non-pest	40

Pollen Beetle	Order Coleoptera	Pest	101
Slug	sp. *Deroceras reticulatum*	Pest	107
Snail	Class Gastropoda	Pest	78
Fly	Order Diptera	Pest	611
Larva (other)	Class Insecta	Pest	66
Caterpillar	Order Lepidoptera	Pest	3
Cranefly	Superfamily Tipuloidea	Pest	24
Mite	Class Arachnida	Pest	12

Table 3. Invertebrates sampled in sweep netting across all years.

Common Name	Taxonomy	Classification	Total Number Observed
Grasshopper	Suborder Caelifera	Non-pest	4
False Blister Beetle	Family Oedemeridae	Non-pest	8
Hoverfly	Family Syrphidae	Non-pest	76
Soldier Beetle	Family Cantharidae	Non-pest	78
Ladybird (inc. larvae)	Family Coccinellidae	Non-pest	367
Lacewing	Suborder Hemerobiiformia	Non-pest	47
Honeybee	sp. *Apis mellifera*	Non-pest	9
Parasitic Wasp	Suborder Apocrita	Non-pest	833
Vespid (other)	Family Vespidae	Non-pest	23
Spider	Order Araneae	Non-pest	147
Harvestman	Order Opiliones	Non-pest	35
Beetle (other)	Order Coleoptera	Non-pest	44
Swollen Thighed Beetle	sp. *Oedemera nobilis*	Non-pest	72
True Shield Bug	Superfamily Pentatomoidea	Non-pest	94
Bumble Bee	Genus *Bombus*	Non-pest	4
Red Wood Ant	sp. *Formica rufa*	Non-pest	8
Weevil (other)	Superfamily Curculionoidea	Non-pest	11
Meadow Plant Bug	sp. *Leptopterna dolabrata*	Non-pest	26
Small True Bug	Suborder Heteroptera	Non-pest	137
Cricket	Superfamily Grylloidea	Non-pest	7
Damselfly	Suborder Zygoptera	Non-pest	19
Tortoise Beetle	Subfamily Cassidinae	Non-pest	1
Larger True Fly	Order Diptera	Pest	2689
Midge	Suborder Nematocera	Pest	281
Common Green Capsid	sp. *Lygocoris pabulinus*	Pest	133
Turnip Flea Beetle	sp. *Phyllotreta nemorum*	Pest	7
Pollen Beetle	Order Coleoptera	Pest	1009
Cabbage Stem Weevil	sp. *Ceutorhynchus pallidactylus*	Pest	23
Tarnished Plant Bug	sp. *Lygus lineolaris*	Pest	14
Cranefly	Superfamily Tipuloidea	Pest	120
Red Mite	Class Arachnida	Pest	40
Capsid (other)	Family Miridae	Pest	21
Robber Fly	Family Asilidae	Pest	26
Leafhopper	Family Cicadellidae	Pest	657
Moth	Order Lepidoptera	Pest	21
Caterpillar	Order Lepidoptera	Pest	89

Large Brown Leaf Hopper	sp. *Nilaparvata lugens*	Pest	14
Flea Beetle	Subfamily Galerucinae	Pest	12

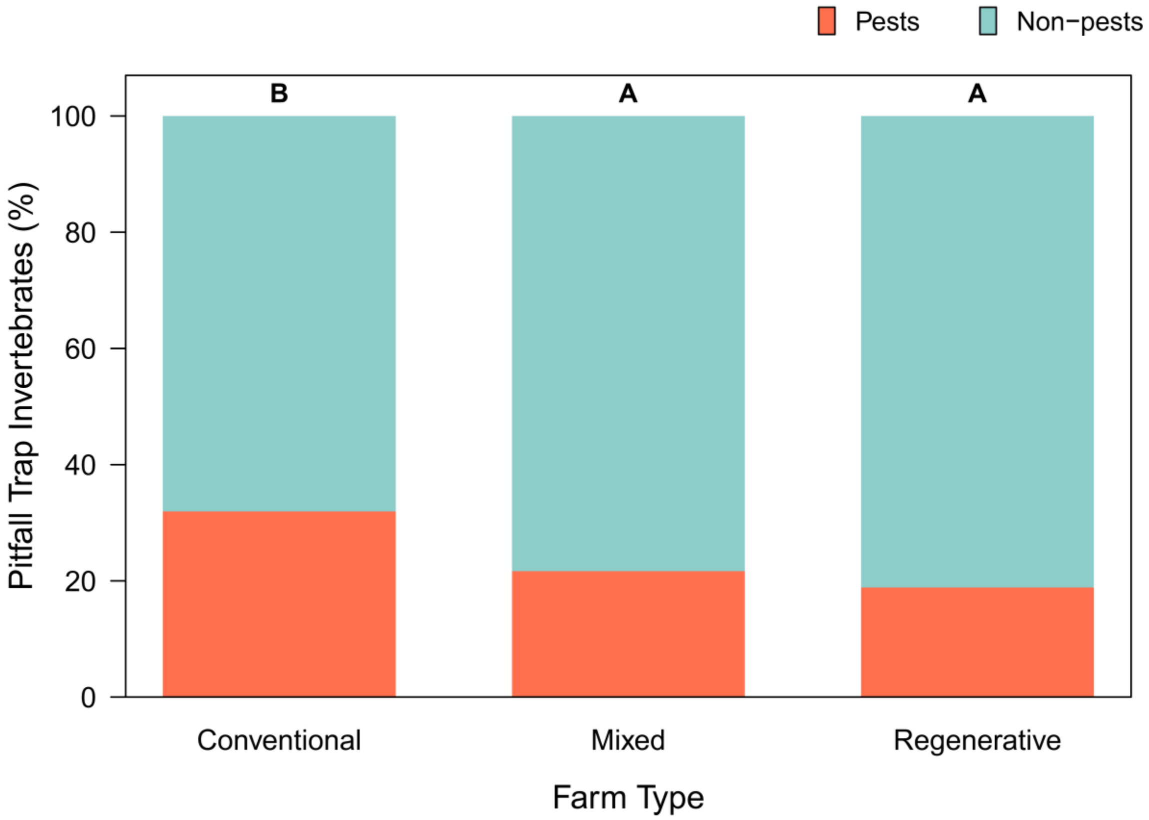

Figure 29. Mean percentage of pest and non-pest invertebrates collected through pitfall traps within different farming systems, across all years. Letters indicate statistically significant differences between means.

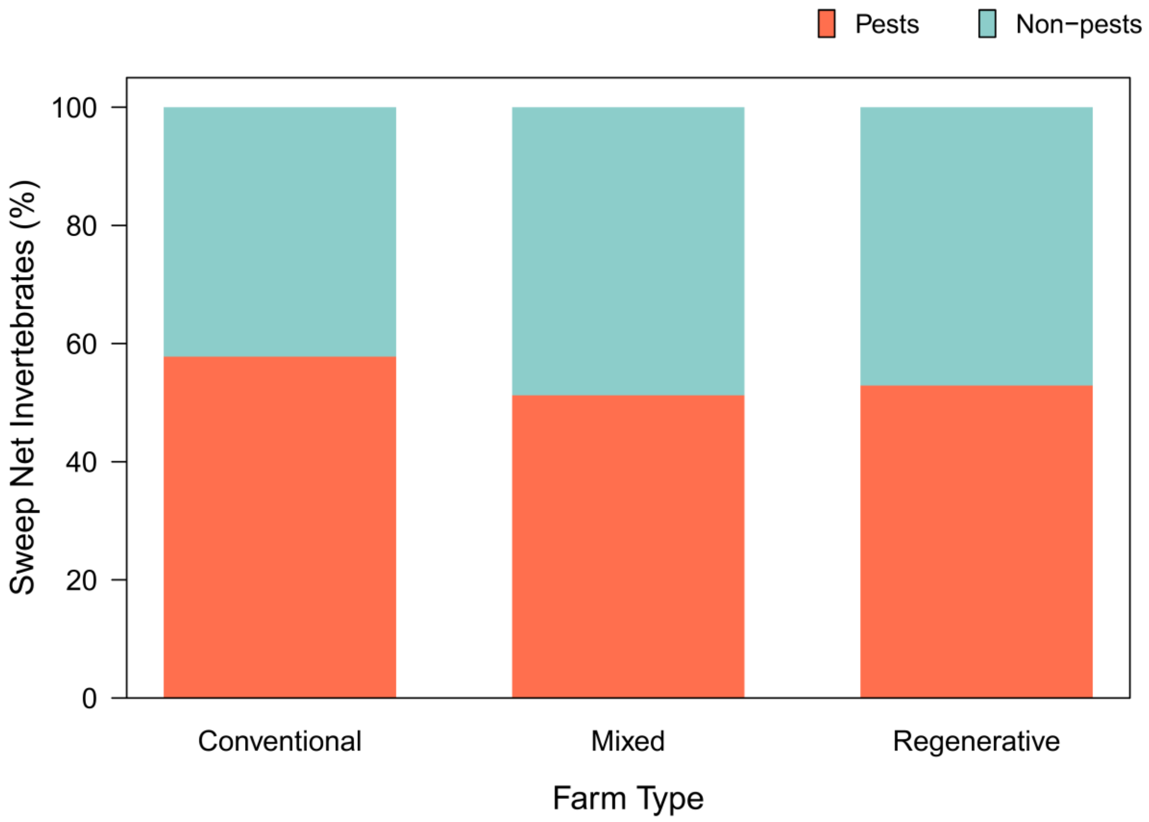

Figure 30. Mean percentage of pest and non-pest invertebrates collected through sweep netting within different farming systems, across all years.

Farmer engagement

The scientists at PGRO have strong expertise in farmer-led trials. All research projects are developed and co-designed with farmer networks to produce relevant crop production solutions. All experimental trials were held on commercial farms to enable large-scale operations to be carried out, together with evaluation by farmers, as well as scientists. Across the years of this project the farmers were instrumental in helping to adapt the direction of the project.

In the final year of the project in 2023, a demonstration plot trial was conducted at the PGRO trial ground in Stubton, Lincolnshire to promote the project and disseminate early outcomes. This was demonstrated on the 27th of June 2023 and was well attended by growers and agronomists. Trial plots are shown in Figure 31.

Figure 31. Demonstration trial near Stubton, Lincolnshire, 27th June 2023.

The conventional grower whose sites included HH, WW, ALC was instrumental in helping to design the trials based on his farms. He drilled the early spring sown trap crop in two fields in 2021, allowing evaluation of crops with and without pheromone and plant volatile lures. In the second year of the project, he drilled three fields with the early spring sown trap crop allowing multiple comparisons of a field with lures against two fields without lures and one spring bean field with no trap crop. In 2023, the final year of the project, the grower was keen to evaluate the effect of the trap crop from one end of the field to another using a later sown trap crop which was drilled two weeks before the main crop.

The regenerative farmer is the CEO of the Nature Friendly Farming Network, a group of like-minded farmers whose ethos is to put nature at the heart of farming. He wished co-design these trials in conjunction with his own existing trials. At PAP 22 the trial field had long-established beetle banks which were incorporated into our biodiversity survey. The trial was set up so that all sample points were equidistant from the beetle banks.

In the regenerative fields studied, PAP 21 and 22, and ABB 23 had long-established margins of different types (Appendix B *PAP 2021 setup, trials diary and sample points*, Appendix D, and Appendix F). However, the basic approach to farming was the same across all the farms, and none had applied insecticides for at least 10 years prior to the start of the project.

In 2022 there was poor spring bean establishment on the regenerative farm and the grower did not grow beans in 2023. Another farm was used in 2023, within five miles of the original farm, which was part of the Nature Friendly Farming network. The field contained a long-term legume-rich margin alongside spring beans, with a long history of not using insecticides.

In 2021 a third grower was involved in trials: see Appendix A for full details. The approach was a mixed IPM system, incorporating habitats for nature, and using insecticides only when required. A strip of lucerne was established adjacent to a wild bird mix around a field of autumn-sown field beans.

This provided on-farm demonstrations for crop benchmarking and peer-to-peer knowledge sharing. Improved management of the two pests described here was prioritised by advisory panels consisting of farmers and industry members who assist PGRO in the development of our research and development program (PGRO, 2020). The development of techniques targeted to reduce inputs and protect agroecosystems is a priority for farmers.

Discussion

Trap cropping is an integrated pest management technique where one or more crop or non-crop species are planted near to a target crop, with the aim of simultaneously attracting and retaining pest species away from the target crop and increasing the prevalence of natural enemies for biological control (Parolin *et al*., 2012; Sarkar *et al*., 2018). In this study, trap cropping systems were assessed for their effect on bruchid beetle damage, pea and bean weevil damage, and black bean aphid populations within faba bean crops. Conventional farming systems with early-sown faba bean trap crops were compared to regenerative farms with legume-rich flowering margins and tussocky grass margins, and the additional use of attractant lures as a method of increasing pest prevalence in trap crops assessed. Biodiversity within each farming system was analysed and compared to a mixed system.

The use of plant volatile lures as an attractant for bruchid beetles within trap crops did not appear to be effective, with no significant difference in bruchid damage between comparable crops with and without lures. Pheromone lures did appear to be effective at attracting weevils at HH 21, with greater numbers of weevil notches present in a field containing lures than one without (Figure 10). The effect was not limited to the trap crop however, and weevil numbers were elevated throughout the main crop and trap crop, indicating that the pheromone lures may have increased the overall presence of weevils, and ultimately had a negative impact on the crop including the harvestable area. This observation was observed at WW 22 however, where no difference in weevil damage between crops with or without lures was observed (Figure 11). Overall, lures in this study were not effective, or had a negative impact, increasing weevil damage in the main crop and thus this evidence suggests they should not be used in combination with trap crops for the purpose of attracting or retaining pests within trap crops.

Trap crops consisting of early-sown faba beans appeared to be effective for attracting pea and bean weevil, with weevil damage significantly higher in trap crops than main crops for most fields assessed. For WW 22, a negative gradient in both weevil and bruchid damage was observed along a 100m transect, with significantly more pest damage within the trap crops and a decline in damage with distance into the main crop (Figure 14; Figure 21). A similar trend was observed in weevil damage at HH 21, where weevil notches were significantly higher in the trap crop of both fields (Figure 12; Figure 13). The 50m and 100m transects sampled at HH 21 and WW 22, respectively, were not the full widths of the fields however and so it is not possible to conclude whether the directional gradient in pest damage continued for the full cross section of each field. Pest populations are often higher closer to field edges (Nguyen and Nansen, 2018), and this was observed in Field 4 at WW 22, a control crop with no trap crop, which showed significantly more damage at 0m than the rest of the crop, with a decline in damage away from the crop edge. This may indicate a natural gradient of declining pest populations further into the field centres for both trap crops and control crops. If the experiment was repeated, all fields would be sampled using a transect of their full width, to gain a better understanding of the effect of field edges compared to trap crops. At ALC 23 however, the full 600m width of the field was sampled and directional gradients in both weevil and bruchid damage were observed, with damage significantly higher in the early-sown bean trap crops than the main crop (Figure 17; Figure 23). Furthermore, at regenerative farm ABB 23, a full 250m cross section of the field showed weevil numbers that were significantly higher at either end of the field near a legume-rich flowering margin and tussocky grass margin, and lowest in the field centre (Figure 16). This may also indicate a natural edge-effect however. There did not appear to be a difference in the effectiveness of differently composed trap crops, with early-sown beans, and legume-rich flower margins seemingly having a similar effect.

Weevil control using trap crops appears to be time-sensitive, declining in effectiveness from April to May, with results at HH 21, WW 22 and ALC 23 showing an increase in weevil damage between sampled dates (Figure 12; Figure 13; Figure 15; Figure 17). At all sites, weevil damage between 10m and 100m from the trap crops increased between April and May, potentially indicating the movement of weevils further into the main crop from the trap crop as the main crop developed and foliar cover increased. This indicated that the trap crop may have its greatest effect in delaying damage to the main crop during earlier developmental stages and establishment. As a result, trap crops did not appear to be particularly effective at retaining weevils within them for the duration of the crop or pest's growth cycle. Similar results were detailed by Cárcamo and Vankosky (2011), where the initial benefits of a winter-sown pea trap crop were negated by the eventual migration of weevils into the spring-sown main crop in May, causing significant damage and resulting in the requirement for pesticide application. The appearance of weevils in the main crop eventually seems inevitable when using trap crops as an IPM technique. The delay of movement into the main crop may lead to benefits to crop health however, as the crop is most at risk of damage to root nodules when weevils are present at early growth stages.

The importance of aphid control and the subsequent effect of infestations on yield was highlighted. Aphids were shown to be associated with a significant reduction in faba bean yield, with analysis of regenerative site ABB 23 showing an estimated loss of 0.5t/ha with every additional 100 aphids observed (Figure 27). Although the effect of trap crops on aphid populations was mixed between individual sites, overall results did indicate that fields containing trap crops within the conventional farms had significantly fewer aphids than the conventional control crops, or regenerative crops (Figure 28). Although aphids have many natural enemies including predator and parasitoid invertebrates, often their population growth rate is such that it cannot be effectively slowed by the presence of natural enemies (Ben-Issa *et al.*, 2017). In PAP 22 aphid populations were highest between the trap crop and 20m, a pattern which was also observed, almost identically, in the control crop with a perennial flowering field margin in place of a trap crop (Figure 26). This suggests that both these regenerative approaches may attract aphids equally well. However, in PAP 22, both the trap crop and control crop areas were smaller areas of a larger crop (Appendix figure 7), and so it is possible this observed distribution of aphids could be a demonstration of an edge effect, where aphid populations are highest closer to crop perimeters, decreasing further into the centre of the field. This edge effect is well-documented in several species of aphid, and attributed to environmental conditions including favourable microclimates, wind patterns enabling mobilisation, and increased vigour of plants at field edges allowing more effective completion of life cycles (Nguyen and Nansen, 2018; Severtson et al., 2016; Winder et al., 1999). A full cross-section of the entire faba bean crop would be needed to assess this edge effect properly.

Results indicated that a conventional approach where pesticides were used to target aphids managed aphid populations more effectively, however the use of pesticides in conventional farming systems was associated with lower overall biodiversity. Regenerative farming techniques, and in particular the long-term exclusion of pesticides, were associated with higher biodiversity, and a significantly higher mean proportion of non-pest to pest invertebrates in pitfall traps (Figure 29). This may explain why bruchid beetle damage was significantly higher in the conventional farms, where the proportion of beneficial invertebrates was lower. Bruchid beetle damage was significantly decreased by the use of trap crops in conventional farms (Figure 24), however the lowest levels of bruchid beetle damage were observed in the regenerative farms, again, possibly due to the higher proportion of beneficial invertebrates, including parasitoids, which help to control bruchid populations.

Conclusions

In this study, the effects of trap cropping and semiochemical attractant lures as an integrated pest management strategy for bruchid beetle, pea and bean weevil, and black bean aphid was assessed. Results indicated that whilst lures had little to no positive impact on attracting bruchids and weevils to trap crops, trap crops did appear to attract these pests, resulting in significantly reduced damage to main crops in early growth stages, particularly in conventional farming systems where the application of pesticides was more common. Similar gradients in pest damage were observed in control crops however, indicating a potentially comparable effect of field edges. The effectiveness of trap crops appeared to reduce between sampling dates as weevil pests particularly migrated further into main crops between April and May samples.

For the management of bruchid beetles, evidence from this study suggests the exclusion of pesticides was the most effective approach, with regenerative farms having significantly less bruchid damage overall. In conventional systems which utilised pesticides, trap cropping did significantly reduce bruchid damage, but damage was higher than in the regenerative systems. The use of pesticides was more effective at managing aphid populations than the implementation of regenerative farming practices but was associated with lower biodiversity and a significantly higher proportion of pest to non-pest invertebrates. Trap cropping in these conventional systems did increase aphid control above the sole use of pesticides.

In future work, the most effective aspects of the IPM strategies detailed in this study could be assessed, through the establishment of early-sown bean trap crops on regenerative farms. This would allow the combined effect of pesticide exclusion and leguminous trap crops to be assessed, as well as the impact of harbouring natural enemy populations and increasing biodiversity.

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Appendices

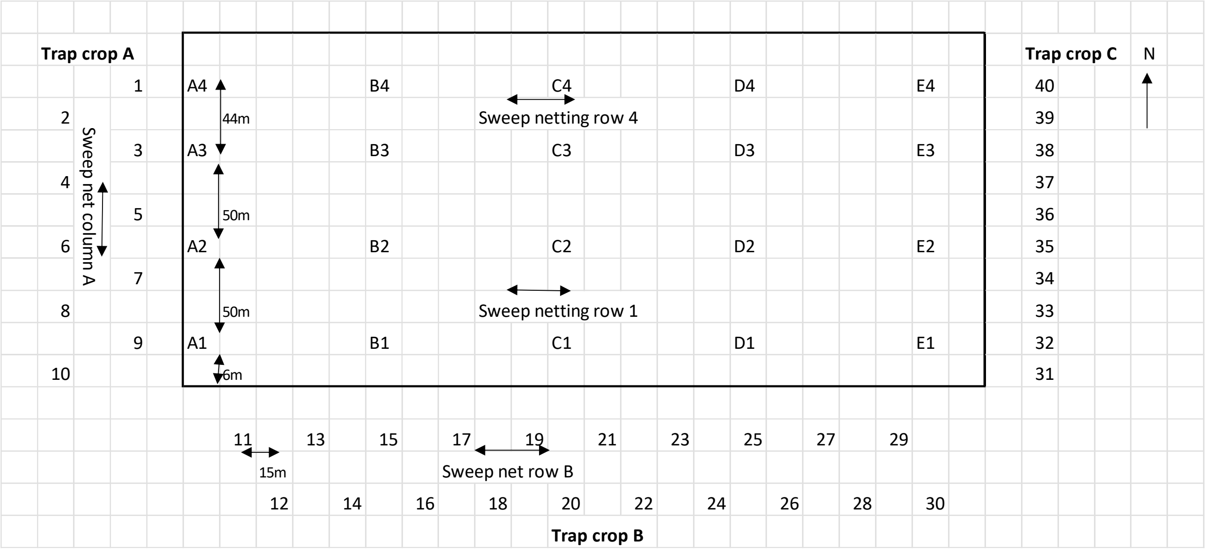
Appendix A MID 2021 setup, trials diary and sample points

Appendix figure 1: Layout of sampling site and points within the main cash crop for evaluation of pest damage at MID in 2021.

A = wild bird mix strip next to crop with lucerne strip next to grass margin and hedge, B = wild bird mix lightly over sown with lucerne, C = grass margin with wildflowers.

Table 4. Trial monitoring diary at MID during the growing season 2021.

Date	BBCH crop growth stage	Assessment type
15/02/2021	12	Weevil station.
02/03/2021	13	Weevil station; weevil notching; plant density.
17/03/2021	14	Weevil station; weevil notching; plant density.
29/03/2021	22	Weevil station; weevil notching; bruchid station.
15/04/2021	31	Weevil station; weevil notching; bruchid station; pitfall traps collected.
26/04/2021	34	Weevil station; weevil notching; bruchid station; pitfall traps collected.
10/05/2021	50	Weevil station; bruchid station; pitfall traps collected.
27/05/2021	63	Weevil station; bruchid station; pitfall traps collected.
10/06/2021	65	Weevil station; bruchid station; pitfall traps collected; sweep net transects.
24/06/2021	67	Weevil station; bruchid station.
09/07/2021	68	Bruchid station; sweep net transects; emergence traps checked.
23/07/2021	87	Emergence traps checked.
02/08/2021	95	Weevil station; bruchid station; emergence traps checked.



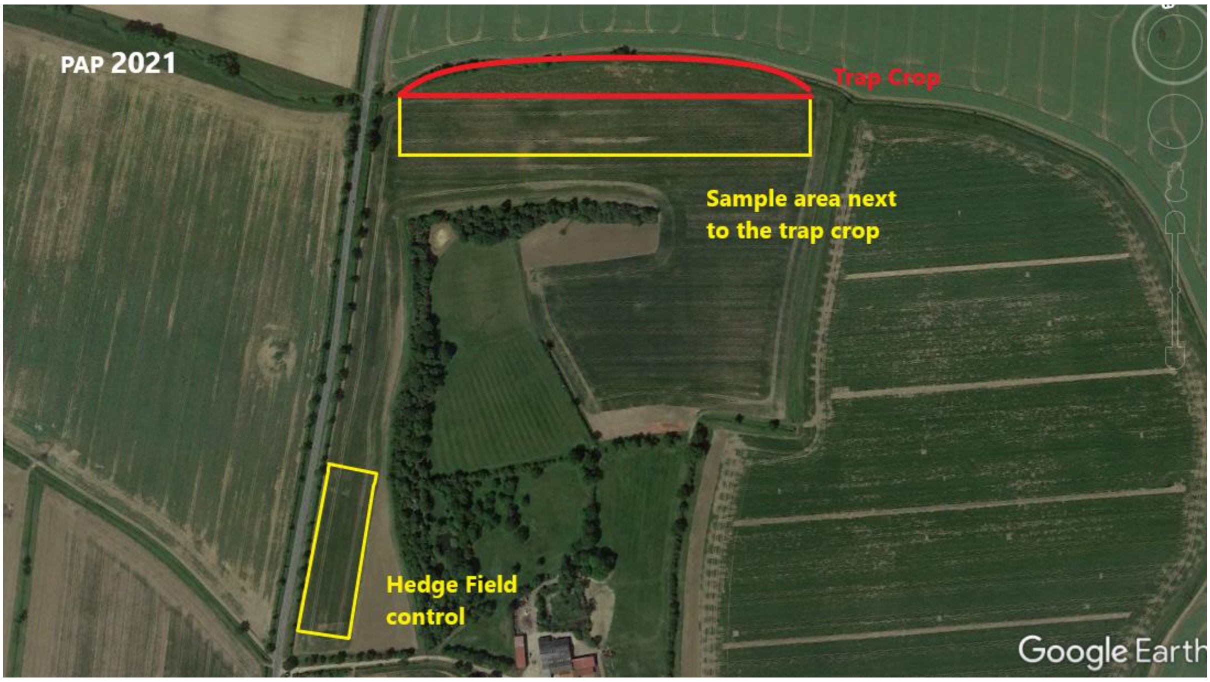
Appendix figure 2. Mid location of sample points and trap crops

Appendix figure 2. Mid location of sample points and trap crops Location of sample points, traps and sweep net transects at MID in 2021.
Weevil and bruchid traps were located 15 metres apart in trap crops A and B in parallel lines 10m apart, and in a straight line in trap crop C. Sweep netting was carried out along parallel lines of 25m length.

Table 5. Location of traps and sweep net transects at MID in 2021.

Pitfall Traps		**Sweep Netting**		**Emergence traps (winter bean main crop only)**
Trap crop	3	Trap crop	Column A	B1
	7		Row B	B2
	12	Winter bean main crop	Row 1	B3
	18		Row 4	B4
	23			D1
	28			D2
	32			D3
	37			D4
Winter bean main crop	A2			
	B1			
	B4			
	C2			
	D1			
	D4			
	E2			

Appendix B PAP 2021 setup, trials diary and sample points



Appendix figure 3. Layout of sampling site at PAP in 2021.

Table 6. Trial monitoring diary at PAP during the growing season 2021.

Date	BBCH crop growth stage	Assessment type
02/03/2021	00	Weevil station.
15/03/2021	00	Weevil station.
26/03/2021	00	Weevil station.
13/04/2021	03	Weevil station; bruchid station.
27/04/2021	10	Weevil station; bruchid station; pitfall traps collected.
11/05/2021	12-13	Weevil station; bruchid station; pitfall traps collected; weevil notching; plant density.
25/05/2021	32	Weevil station; bruchid station; pitfall traps collected; weevil notching; plant density.
07/06/2021	60	Weevil station; bruchid station; pitfall traps collected.
21/06/2021	67	Weevil station; bruchid station; sweep net transects.
05/07/2021	72	Bruchid station; sweep net transects; emergence traps checked.
20/07/2021	80	Bruchid station; sweep net transects; emergence traps checked.
02/08/2021	89	Bruchid station; sweep net transects; emergence traps checked.
24/08/2021	97	Bruchid station; emergence traps checked.

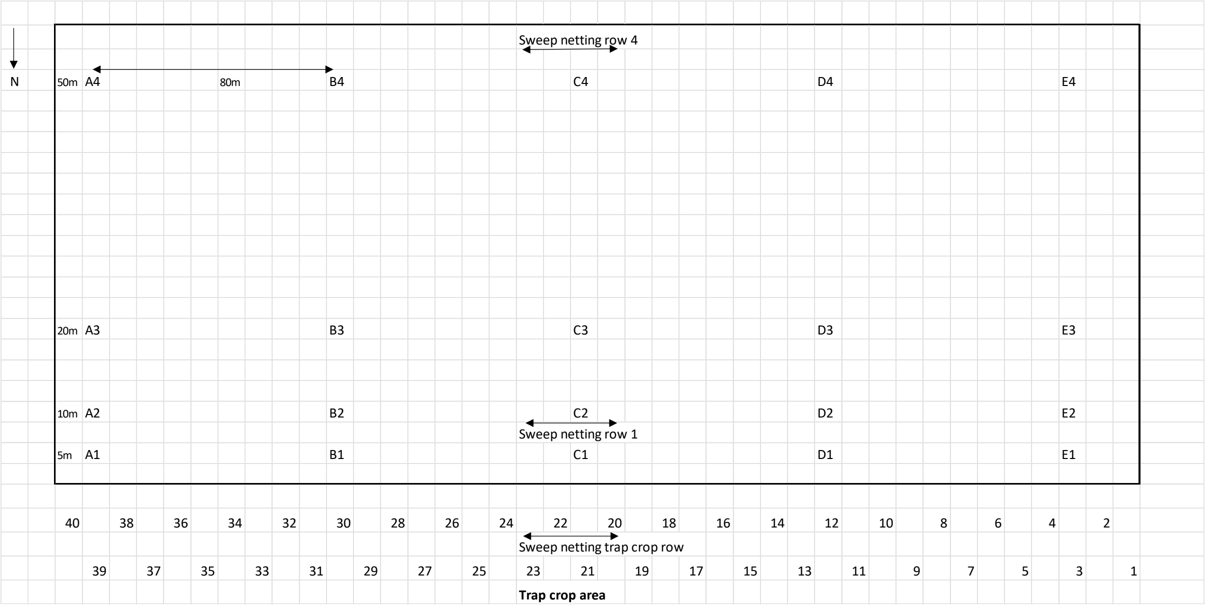
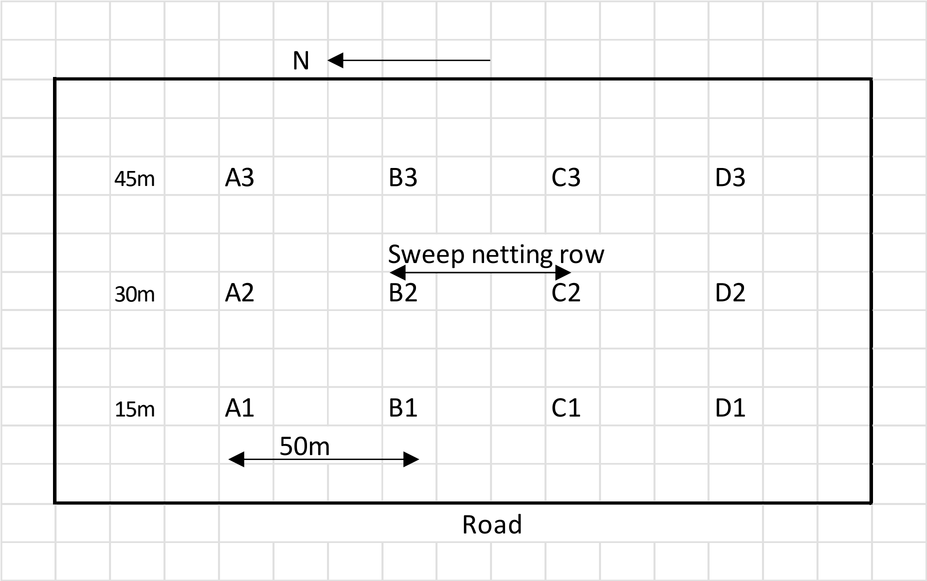


Table 7. Location of sample points, traps and sweep net transects in the trap crop field at PAP in 2021.

Weevil and bruchid traps were located 12 metres apart in the trap crop in parallel lines 10m apart. Sweep netting was carried out along parallel lines of 25m length.

Table 8. Location of traps and sweep net transects at PAP in 2021.

Pitfall Traps		**Sweep netting**		**Emergence traps**
Trap crop	3	Trap crop	See figure II	B1
	8	Spring bean main crop	Row 1	B2
	13		Row 4	B3
	18			D1
	23			D2
	28			D3
	33			
	38			
Spring bean main crop	A2			
	A4			
	B1			
	C3			
	D2			
	E1			
	E4			



Appendix figure 4. Location of sample points and sweep net transects in Hedge field at PAP in 2021.

Table 9. Location of sweep netting transects and emergence traps for Hedge field at PAP in 2021.

Sweep Netting	Emergence traps
Centre row	B1
	B2
	B3

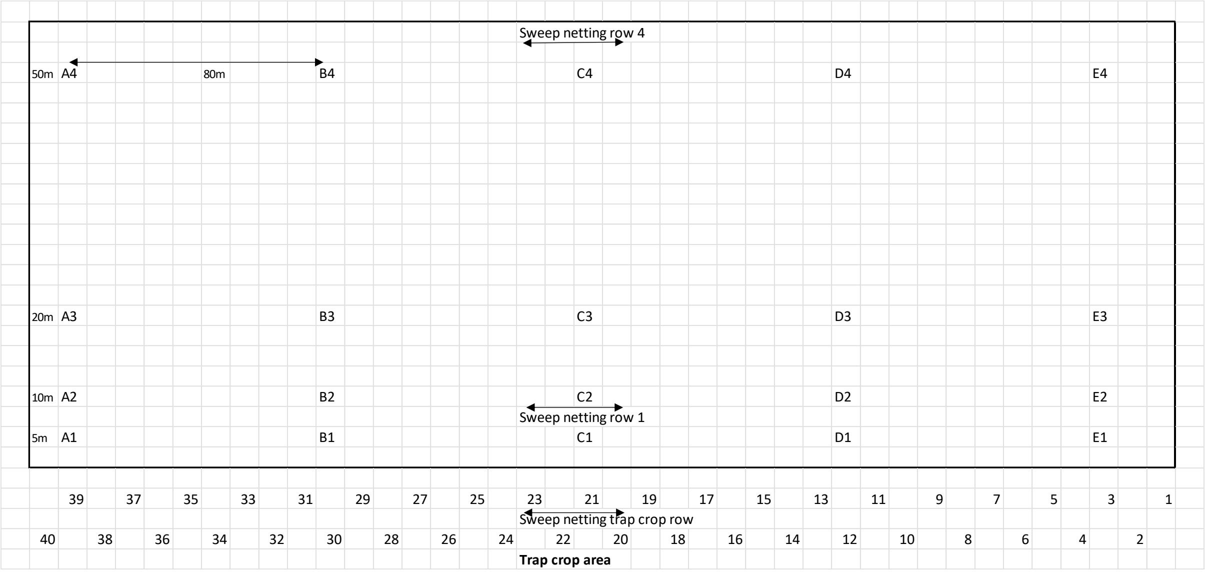
Appendix C HH 2021 setup, trials diary and sample points

Appendix figure 5. Layout of sampling site at HH in 2021. Field 9 trap crop area was January-sown spring beans without lures. Field 10 trap crop area was January-sown spring bean with lures.

Table 10. Trial monitoring diary at HH during the growing season 2021.

Date	BBCH crop growth stage	Assessment type
18/03/2021	Trap crop 12 Main crop not emerged	Weevil station.
26/03/2021	Trap crop 13 Main crop not emerged	Weevil station.
14/04/2021	Trap crop 14 Main crop 09	Weevil station; bruchid station.
29/04/2021	Trap crop 15 Main crop 12	Weevil station; bruchid station; pitfall traps collected; weevil notching; plant density.
12/05/2021	Trap crop 34 Main crop 13	Weevil station; Bruchid station; pitfall traps collected; weevil notching.
26/05/2021	Trap crop 61 Main crop 32	Weevil station; bruchid station; pitfall traps collected.
12/06/2021	Trap crop 64 Main crop 61	Weevil station; pitfall traps collected. Sweep net transects.
22/06/2021	Trap crop 70 Main crop 63	Weevil station; bruchid station; sweep net transects.
07/07/2021	Trap crop 83 Main crop 67	Bruchid station; emergence traps checked. Sweep net transects.
23/07/2021	Trap crop 87	Bruchid station; sweep net transects; emergence traps checked.

	Main crop 74	
03/08/2021	Trap crop 92 Main crop 77	Weevil station; bruchid station; sweep net transects; emergence traps checked.
24/08/2021	Trap crop 97 Main crop 93	Emergence traps



Appendix figure 6. Location of sample points, traps and sweep net transects at HH fields 9 and 10 in 2021.

Weevil and bruchid traps were located 12 metres apart in the trap crop in parallel lines 10m apart in field 10 only. Sweep netting was carried out along parallel transects of 25m length.

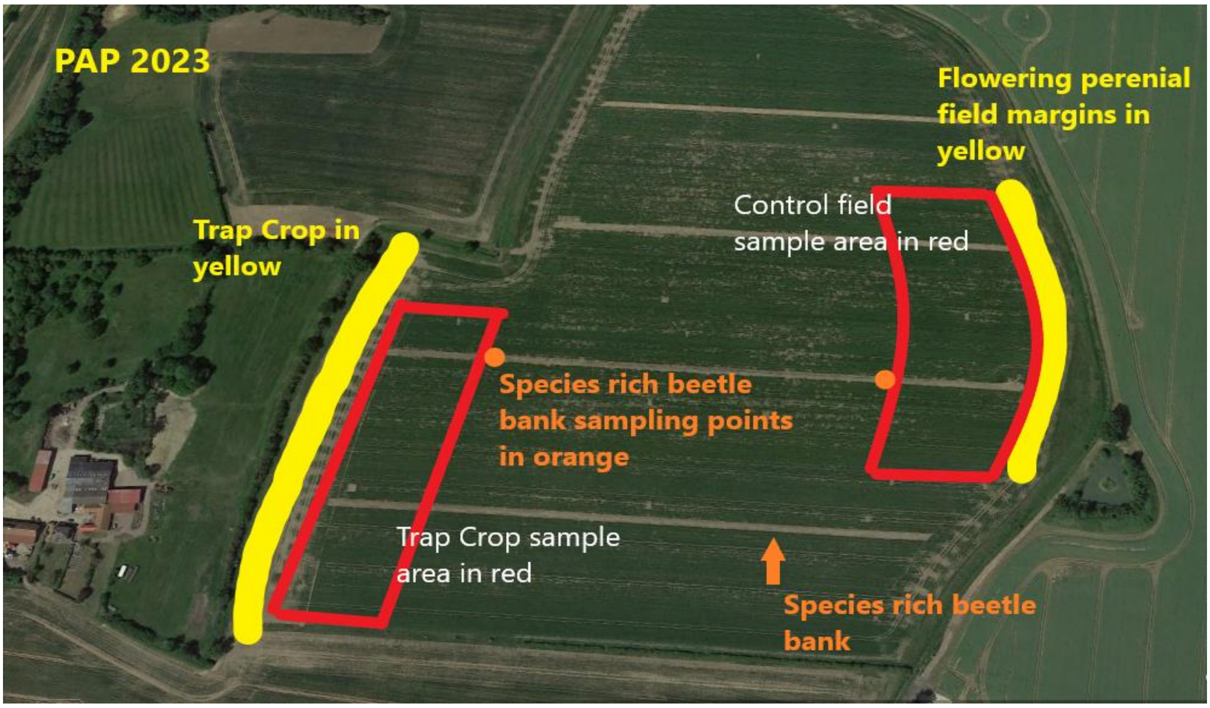
Table 11. Location of pitfall traps in field 10 at HH in 2021.

Pitfall traps	
Spring bean trap crop (sown January 2021)	B3
	A8
	B13
	A18
	B23
	A28
	B33
	A38
Spring bean main crop (sown April 2021)	A2
	A4
	B3
	C1
	D4
	E2
	E3

Table 12. Location of sweep netting transects and emergence traps in both fields 9 and 10 at HH in 2021.

Sweep netting		**Emergence traps**	
Spring bean trap crop (sown January 2021)	Trap crop row	Spring bean trap crop (sown January 2021)	In line with column B
Spring bean main crop (sown April 2021)	Row 1		In line with column D
	Row 4	Spring bean main crop (sown April 2021)	Between B2 and B3
			B4
			Between D2 and D3
			D4

Appendix D PAP 2022 setup, trials diary and sample points

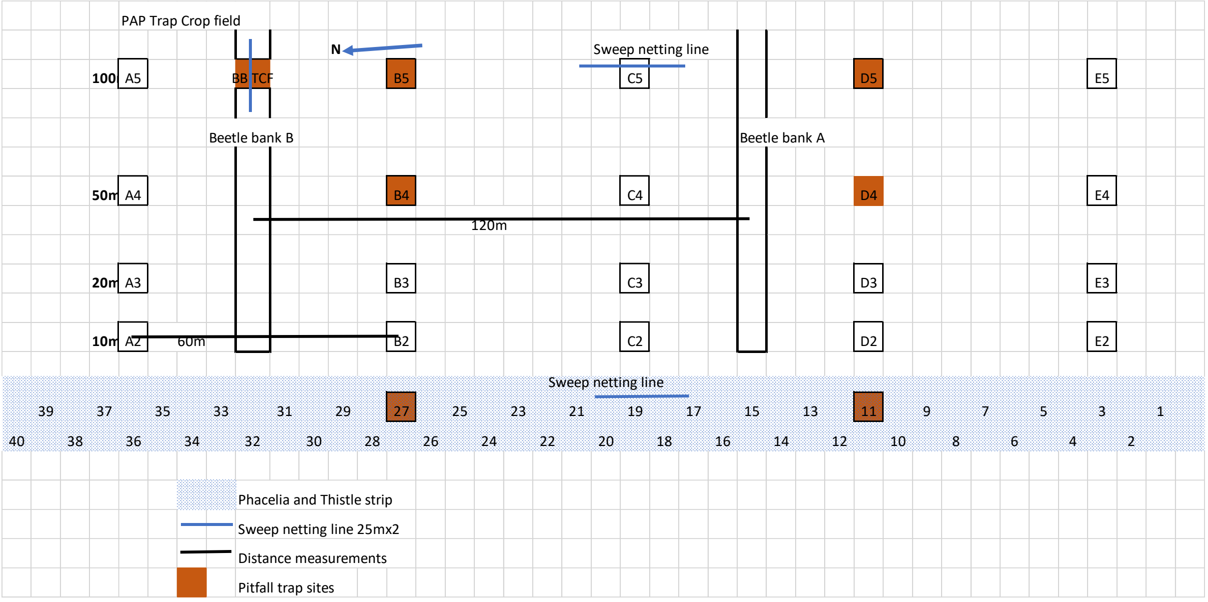


Appendix figure 7. Layout of sampling locations and field margins of both areas at PAP, 2022

This includes the sampling areas adjacent to the trap crop, and the control area which was adjacent to a flowering field margin. Running between the two areas approx. every 60m within the field was a tussock grass, species rich beetle bank No insecticides were applied at PAP.

Table 13. Trial monitoring diary at PAP during the growing season 2022.

Date	**BBCH Crop Growth Stage**	**Assessment type**
29/03/2022	00	Weevil station
12/04/2022	00	Weevil station
26/04/2022	03	Weevil station, bruchid station
13/05/2022	12	Weevil station, bruchid station, weevil assessment, plant density
24/05/2022	15-17	Weevil station, bruchid station, weevil assessment,
10/06/2022	15-59	Weevil station, bruchid station, pitfall traps collected
24/06/2022	55-62	Bruchid station, pitfall traps collected, sweep netting
08/07/2022	67-69	Aphid assessments, Sweep netting
22/07/2022	80-85	Sweep netting
10/08/2022	95-97	Harvest samples



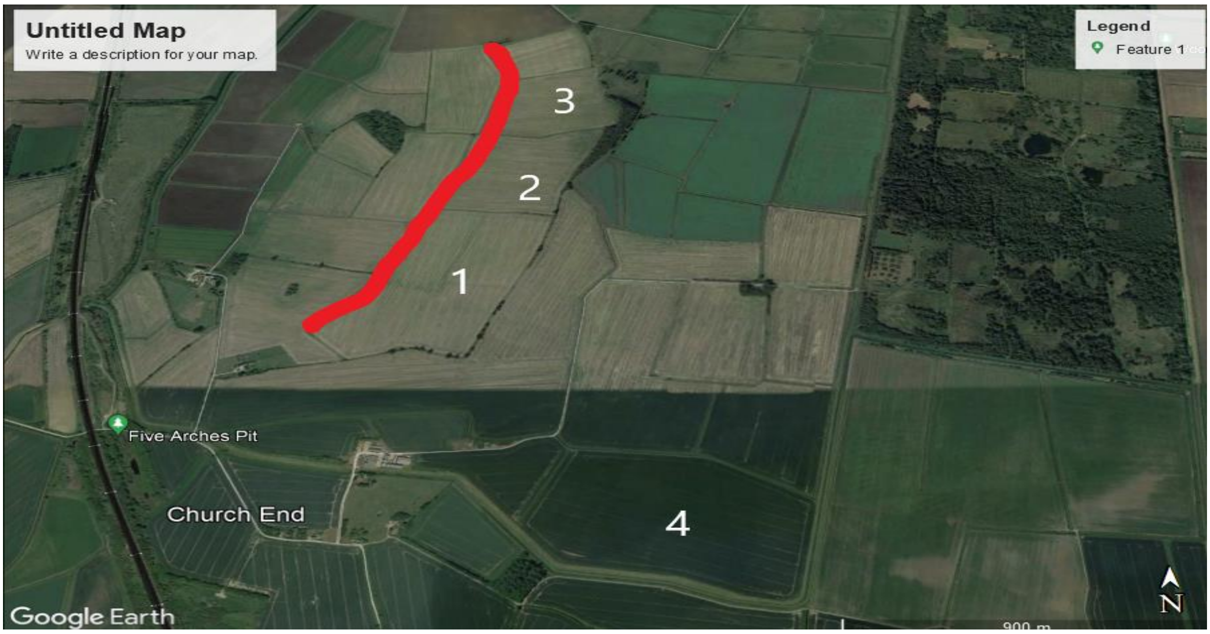
Appendix figure 8. Location of sample points, traps and sweep net transects in the trap crop field at PAP in 2022.

Weevil and bruchid traps were located 8m metres apart in the trap crop in parallel lines 10m apart. Sweep netting was carried out along parallel lines of 25m length. Control field was set up the same, except the orientation of North was opposite.

Table 14. Location of traps and sweep net transects at PAP2022, in both the trap crop and control field areas.

Pitfall Traps		**Sweep netting**	
Trap crop	B1 D1	Trap Crop	C1
Spring bean main crop	B5 D5	Spring bean main crop	C5
Beetle Bank B Either 100m from trap crop or control crop	100m	Beetle Bank B Either 100m from trap crop or control crop	100m

Appendix E WW 2022 setup, trials diary and sample points



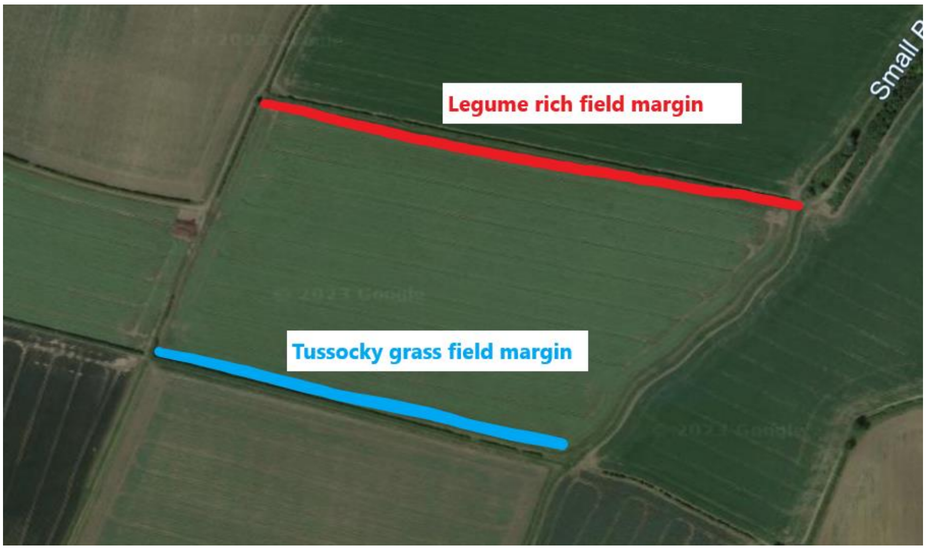
Appendix figure 9. Layout of sampling site at WW. The thick red line = trap crop area.

Field 1 trap crop area was January-sown spring bean strip containing 40 lure stations. Field 2 trap crop area was January-sown spring beans. Field 3 trap crop area was January sown spring beans. Field 4 contained no trap crop area and March sown Spring beans only as the main crop. Field 3 at WW was sprayed with lambda-cyhalothrin, a pyrethroid, on 13th June 2022, to control bruchid beetle. All fields at WW were sprayed with pirimicarb on 24th June2022 to control aphids.

Table 15. Trial monitoring diary at WW during the growing season 2022.

Date	BBCH Crop Growth Stage	Assessment type
29/03/2022	Trap crop 13 Main crop 00	Weevil station
12/04/2022	Trap crop 15 Main crop 05	Weevil station
25/04/2022	Trap crop 22-33 Main crop 12	Weevil station, bruchid station, weevil assessment, plant density
10/05/20022	Trap crop 51-53 Main crop 32	Weevil station, bruchid station, weevil assessment
23/05/2022	Trap crop 55-60 Main crop 50-52	Weevil station, bruchid station, pitfall traps collected
10/06/2022	Trap crop 62-65 Main crop 60	Weevil station, bruchid station, pitfall traps collected, sweep netting
23/06/2022	Trap Crop 80 Main crop 69	Bruchid station, pitfall traps collected, sweep netting, aphid assessments
07/07/2022	Trap crop 85 Main crop 77	Bruchid station, Sweep netting
08/08/2022	Trap crop 97 Main crop 95	Harvest samples

Appendix F ABB 2023 setup, trials diary and sample points

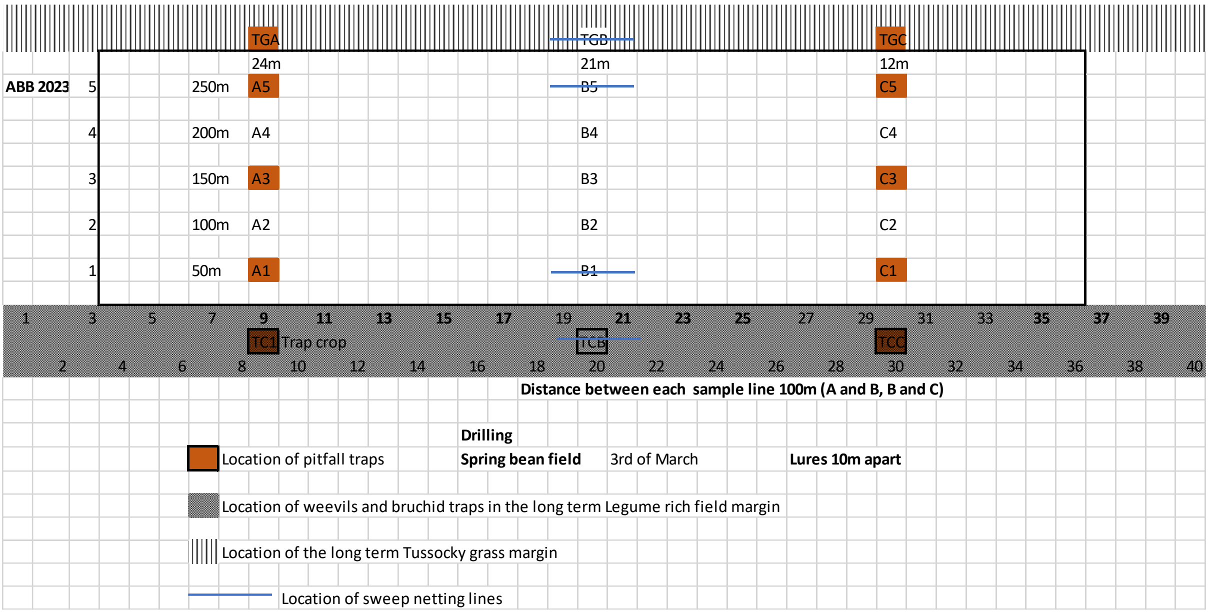


Appendix figure 10. Layout of field margins at either end of the field at ABB. The control area was adjacent to a tussocky grass field margin.

No insecticides were applied at ABB.

Table 16. Trial monitoring diary at ABB during the growing season 2023.

Date	BBCH Crop Growth Stage	Assessment type
30/03/2023	00	Weevil station.
20/04/2023	12-13	Weevil station, weevil damage assessment, plant density.
04/05/2023	14-33	Weevil station, bruchid station, weevil damage assessment.
15/05/2023	16-17-34	Weevil station, bruchid station.
30/05/2023	62	Weevil station, bruchid station, pitfall traps.
15/06/2023	67	Weevil station, bruchid station, pitfall traps, aphid assessment, sweep netting.
26/06/2023	73	Pitfall traps, sweep netting, aphid assessment.
13/07/2023	77	Sweep netting.
22/07/2023	80	Sweep netting.
23/08/2023	95-97	Harvest samples.



Appendix figure 11. Location of sample points, traps and sweep net transects in the trap crop field at ABB in 2023.

Weevil and bruchid traps were located 10m metres apart in the legume rich field margin in parallel lines. Sweep netting was carried out along parallel lines of 25m length.

Table 17. Location of traps and sweep net transects at ABB in 2023.

Pitfall Traps		**Sweep netting**	
Trap crop	TCA TCC	Trap Crop	TCB
Spring bean main crop	A1,A3,A5, C1,C3,C5	Spring bean main crop	B1 B5
Tussocky grass margin	TGA TGC	Tussocky grass margin	TGB

Appendix G ALC 2023 setup, trials diary and sample points

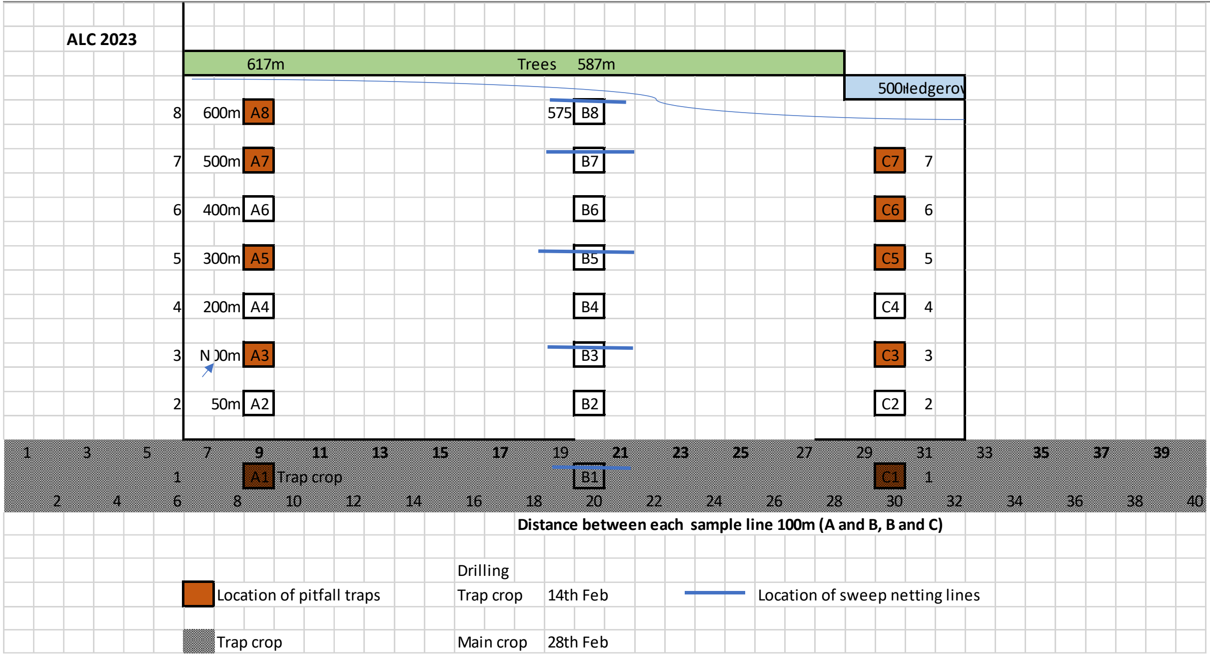
Appendix figure 12. Layout of field scale trial site at ALC 2023.

Red line = trap crop area drilled on the 14th of February 2023. The main spring bean crop was drilled on the 28th of February 2023 The field was sprayed with primicarb on the 15th of June to control aphids.

Table 18 .Trial monitoring diary at ALC during the growing season 2023.

Date	BBCH Crop Growth Stage	Assessment type
03/04/2023	Trap crop 12 Main crop 10	Weevil station.
17/04/2023	Trap crop 13 Main crop 12	Weevil station, weevil damage assessment, plant density.
03/05/2023	Trap crop 16-35 Main crop 14-30	Weevil station, bruchid station, weevil damage assessment.
15/05/2023	Trap crop 55 Main crop 52	Weevil station, bruchid station.
31/05/2023	Trap crop 65-66 Main crop 62-63	Weevil station, bruchid station, pitfall traps.
15/06/2023	Trap crop 68 Main crop 66	Weevil station, bruchid station, pitfall traps, sweep netting, aphid assessment.
26/06/2023	Trap Crop 75 Main crop 71	Bruchid station, pitfall traps, sweep netting, aphid assessment.
13/07/2023	Trap crop 80 Main crop 79	Bruchid station, sweep netting.
25/07/2023	Trap crop Main Crop	Sweep netting.

21/08/2023	Trap crop 97 Main crop 95	Harvest samples.



Appendix figure 13. Location of sample points, traps and sweep net transects at in ALC 2023.

Weevil and bruchid traps were located 10 metres apart in the trap crop. Sweep netting was carried out along parallel lines of 25m length.

Table 19. Location of traps and sweep net transects at all fields at ALC in 2023.

Pitfall Traps		**Sweep netting**		
Trap crop	A1	Trap crop	B1	
	C1	Spring bean main crop	B3, B5, B7, B8	
Spring bean main crop	A3, A5, A7, A8 C3, C5 C6, C7			