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

Annual report for 2022 (year 2)

Funded by the Ekhaga foundation with the Processors and Growers Research organisation.

Dr Becky Howard
Mrs Shona Duffy
Mr Nicolo Vela
Mrs Dina Gomez

Summary

This project seeks to develop an Integrated Pest Management (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 was also studied. Added ecological benefits to agricultural systems contributed by the trap crops, particularly for beneficial insects, were evaluated. Two farm sites were studied in 2022, one of the sites having a trap crop containing lucerne and one farm site containing three fields with early sown spring faba bean trap crops, and one field with no trap crop. Effects of trap crops on pest levels were observed in 2022, and the early sown spring faba bean trap crop appeared to have the clearest effect on pest levels in the main crop.

Table of Contents

List of tables

List of Figures

Introduction

Faba bean (*Vicia faba*) is an essential UK and European crop, but grain yield and quality may be significantly reduced by *Sitona lineatus* (pea and bean weevil) and *Bruchus rufimanus* (bruchid beetle). Pea and bean weevils cause reduction in yield and benefit to the following crop by larval feeding on the nitrogen-fixing root nodules, and bruchid beetles cause damage to the grains in which the larvae feed. The pests have become increasingly difficult to manage in conventional agricultural systems due to restrictions in agrochemical usage, resistance to existing insecticides and climate warming. 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.

In other countries such as France, production 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 become more of a barrier to the production of high-quality faba beans 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 strategies but require thorough testing under commercial-scale field conditions.

One approach is to use perimeter trap crops to attract beetle pests and prevent infestation of the main crop. 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 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. Reduction in damage by pea and bean weevils can also be obtained by delaying sowing (Carcamo *et al*., 2018).

Trap cropping is a traditional technique used to manipulate agricultural ecosystems, providing differential conditions for oviposition, and feeding, and diverting and intercepting target species in order to reduce impact in the main crop (Shelton and Badenes-Perez, 2006). 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. The broader impacts of trap cropping in faba beans on beneficial organisms and other pest management, for example aphids and viruses, will be evaluated. All trials are based in the East Anglian area of the UK.

Methods

Site details

Two sites with different farming regimes and approaches to insect pest management were established in spring 2022 (WW and PAP). Figure 1 shows farm locations and Table 1 summarises the type of farming system at each site. One insecticide spray was applied at WW on the 24th of June to control aphids, but none were applied at PAP in 2022. At each location 40 pheromone and 40 plant volatile bait stations (traps) were located within the trap crop field

Figures 2 and 3 show the location of the trap crop at WW and PAP. Appendix A shows the layout of additional sampling points at all sites, type of trap cropping, and method of sampling used.

At site WW there three fields contained trap crops and one did not. Of the three trap crop fields, Field 1 contained pheromone and plant volatile lures and Fields 2 and 3 did not. Field 4 did not contain a trap crop (Figure 2). The trap crops at WW were field beans sown in January 2022, and the main crops were spring field beans sown in March 2022.

At site PAP, main crop spring field beans were sown in April 2022. Figure 3 shows the area used for sampling adjacent to the trap crop, a long-term legume-rich margin that included lucerne. A separate area of the field was used as a control comparison, although this was adjacent to a flowering perennial field margin. The two sample areas were interconnected by beetle banks, where sampling using sweep netting and pitfall trapping was conducted to determine biodiversity compared to the rest of the field.

Each bait station contained a pheromone or plant volatile lure. These were checked every 2 weeks and numbers of insects recorded. Details of trap orientation and sampling points can be found in Tables 2 and 3.

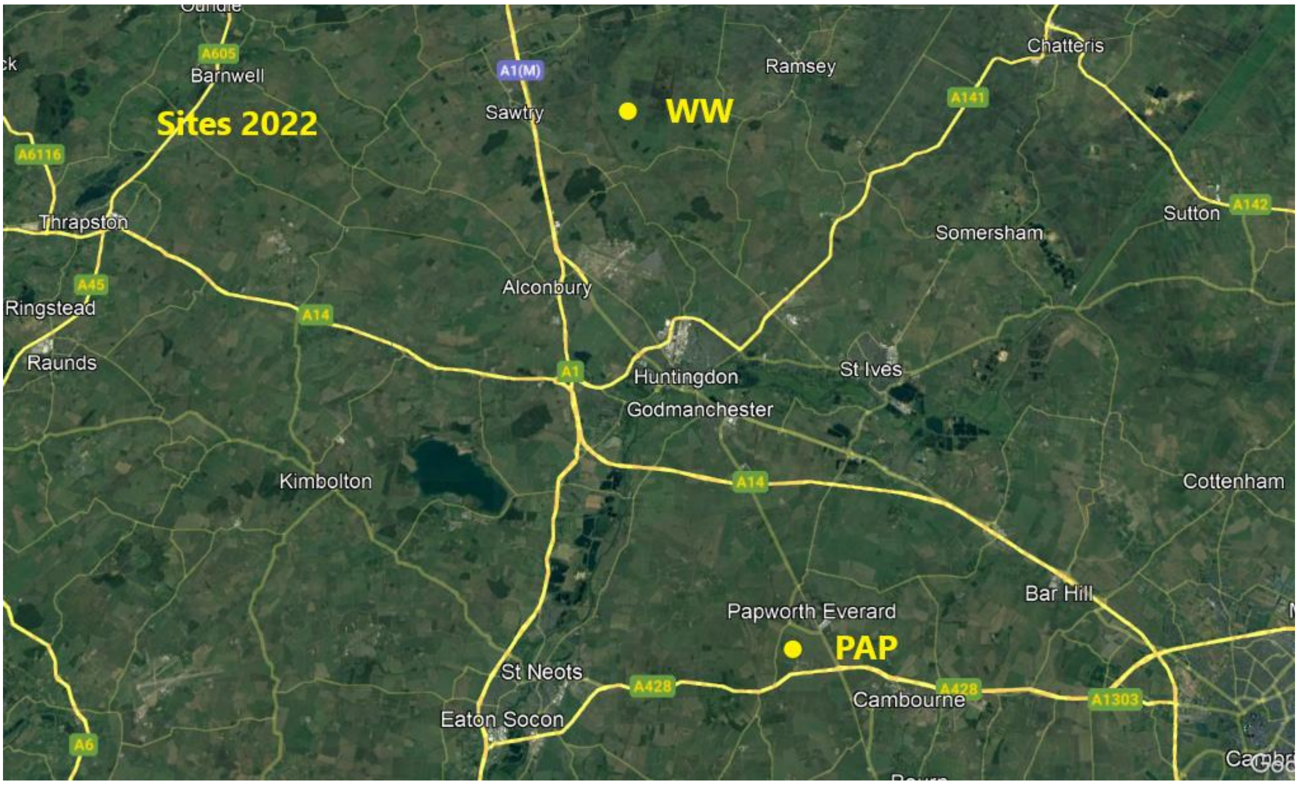


Figure 1. Map of the location of trap crop farm sites in 2022.

Table 1. Farm details for the trap cropping sites in 2022

Site reference	Location (OS grid reference)	Cultivation System	Whole farm spray regime	Insecticides applied on trap crop fields	Crop	Trap crop details	Crop sown
PAP	TL 2761 7836	Direct drill	No insecticides	0	Spring Beans	Long-term legume rich field margin	1st April 2022
WW	WW	Plough	Standard spray programme	2 see below	Spring Beans	January-sown strip of spring beans	21st March 2022

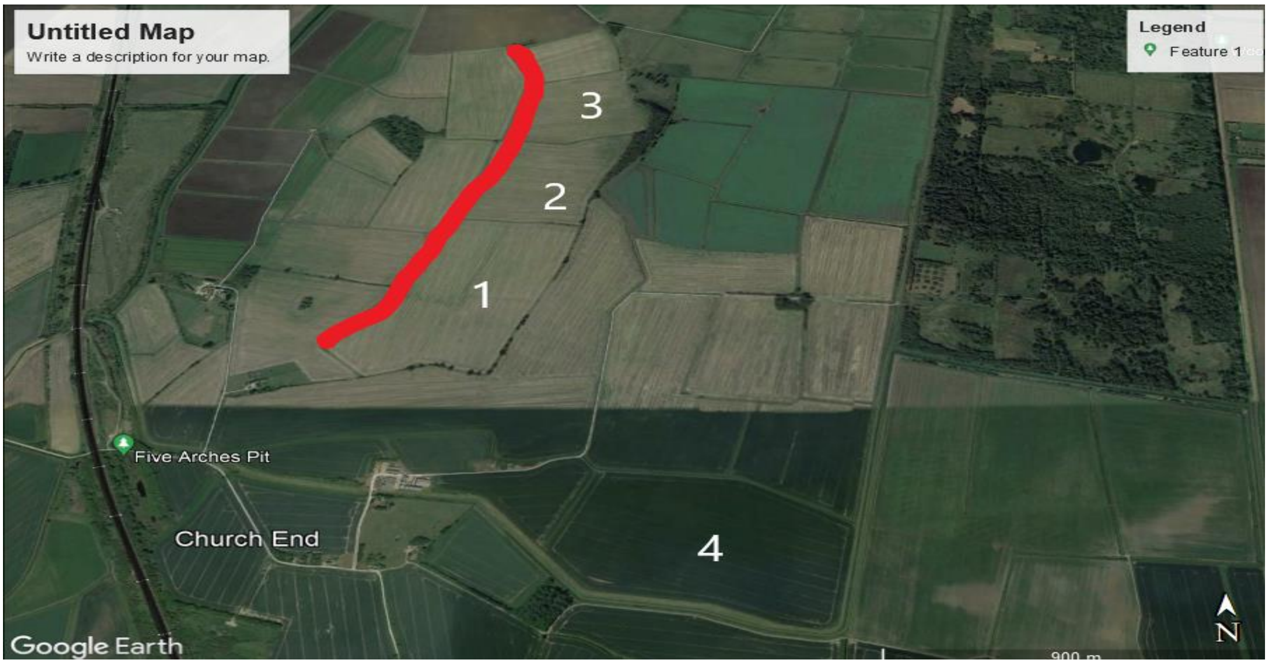


Figure 2. Layout of sampling site at WW. The thick red line = trap crop area. Field 1 trap crop area was January-sown spring bean strip containing 40 lure stations. Field 2 trap crop area was January-sown spring beans. Field 3 trap crop area was January sown spring beans. Field 4 contained no trap crop 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 June to control aphids. No insecticides were applied at PAP.

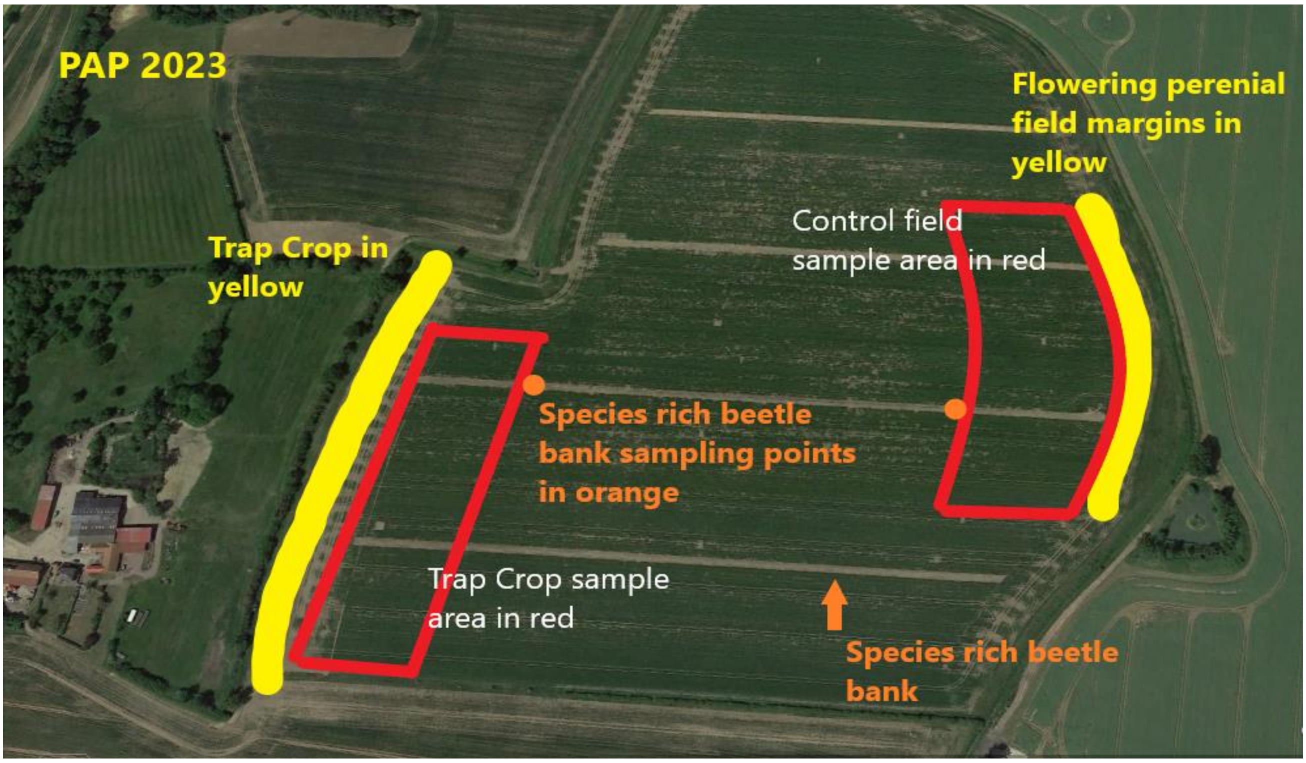


Figure 3. Layout of sampling locations and field margins of both areas at PAP, including the sampling areas adjacent to the trap crop, and the control area which was adjacent to a flowering field margin. Running between the two areas approx. every 60m within the field was a tussock grass, species rich beetle bank.

Tables 2 and 3 show the timing of assessments or collections for all monitoring activities for the duration of the season at each site.

Table 2. 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

Table 3. 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

Plant density

Plant density was calculated by recording the number of plants in three 1/3m^2 quadrats at each sample point at each site.

Pest pheromone and plant volatile stations

S. lineatus (pea and bean weevil) pheromone baited stations

S. lineatus (pea and bean weevil) pheromone baited stations were placed within the trap crops and secured by canes at ground level (Figure 4). 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, one closer to the main crop and one further away so that the bait stations were offset by approximately 10 metres. The traps were checked every two weeks and the number of weevils captured was recorded. Details of location of traps at each site can be found in Appendix A.

a b

Figure 4. **a.** Pea and bean weevil pheromone baited station in situ. **b.** pea and bean weevil adult feeding on foliage

B. rufimanus (bruchid beetle) plant volatile bait stations

B. rufimanus bait stations were placed within the trap crops and secured on canes at 1 metre height (Figure 5). 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, one closer to the main crop and one further away so that the bait stations were offset by approximately 10 metres. 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.

a b

Figure 5. 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 25 plants at each sampling point in the main crop on at least two occasions following emergence of the crop (Figure 6).

Figure 6. 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. Ten plants were collected from each of the 20 assessment/ sampling points within the main crop at each site, and at WW five additional samples were taken from each of the trap crops, corresponding with lines A to E (Appendix A). Pods were removed from the plants and seeds removed from pods. These were weighed and moisture content was measured. Samples were processed and seed was evaluated for damage caused by bruchid beetles. Seeds were cut open and examined for the presence of larvae or adults (EPPO guidance PP 1/175 (2)), and damage is also characterised by a circular exit hole or circular clear 'window' on the seed surface and brown markings on the seed surface (Figure 7).

Figure 7. Bruchid adult emerging from seeds at maturity.

Aphid assessment

On 23rd June 2022 at WW, prior to the aphicide application, and 8th July at PAP, aphid assessments were carried out within the crop. At each sampling point aphids were recorded on 20 plants, and mean number of aphids per plant calculated.

Emergence traps

Emergence traps were evaluated in 2021 but the results were inconclusive, and they were not used in 2022.

Biodiversity monitoring

Sweep netting

Appendix A gives details of the location of the sweep net transects, and Tables 2 and 3 details of the timing of sweep netting at each site. 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 8). The contents of the 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, and recorded.

Figure 8. Sweep netting insect 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 in all 4 fields at the WW site. At PAP they were placed in the trap crop, main crop, control area and beetle bank (Appendix A). These 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 insects to enter the traps (Figures 9 and 10). These were emptied after two days into a resealable labelled bottle, returned to the laboratory, and refrigerated for a period until identification and recording of insects took place.

Figure 9. Pitfall trap in situ.

Figure 10. Raised cover over pitfall trap to prevent rainfall inundation.

Yield

At BBCH growth stage 97, harvest samples were taken at each site. Ten plants were collected from each of the 20 assessment/ sampling points within the main crop at each site, and at WW five additional samples were taken from each of the trap crops, corresponding with lines A to E (Appendix A). Pods were removed from the plants and seeds removed from pods. These were weighed and moisture content was measured. Yield was calculated as tonnes per hectare for each sampling point, considering the plant density counts carried out at early crop growth stages.

Data recording and analysis

An estimation of the diversity of insect species was calculated using the Simpson Diversity Index for all insects collected while sweep netting and in pitfall traps at each site and between sites.

The Simpson Diversity Index (D) was calculated using the formula:

$D = 1 - \Sigma ni(ni-1) \; / \; N(N-1)$,

Where:

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

The value of the Simpson Index ranges between 0 and 1 and the higher the number, the greater the biodiversity.

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. Graphical representations were produced as heat maps for each site to illustrate the distribution of damage across the field for each pest.

Regression analysis was undertaken to determine associations between pest damage and yield for each site, using Microsoft Excel.

One-tail t-test analysis was performed where possible to determine whether there was a significant difference in yield or pest damage between the fields containing the trap crop and the control area for PAP sites only to determine if the presence of the trap crop influenced these factors. The analysis was carried out using Microsoft Excel.

To compare fields at WW, the variables were analysed using ANOVA to establish any significant differences, using Microsoft Excel. The significant data sets were then further analysed using Tukey's HSD in R statistical software.

Results

Pest damage and yield at all sites 2022.

Mean pest damage was calculated for each sampling point at each site and regression analysis undertaken to determine whether there was a relationship between damage and yield. The results showed that there were significant associations between the mean number of weevil notches per plant at the first assessment and yield, at WW fields 1 and 4. At PAP there were significant associations between weevil damage and yield at assessment 2 in both fields (Table 4). There was a significant association between mean percentage bruchid damage and yield at WW field 1 and PAP control field, although this may not be a direct association, but related to another factor, such as plant density or vigour, that also affects yield. There were no significant associations between aphid numbers and yield at any of the sites (Table 4). R^2 values for significant associations indicated that only a small percentage of the variation is explained by either weevil or bruchid damage (Table 4).

Table 4. Regression analysis for all sites, comparing pest damage from pea and bean weevils, bruchid beetles and aphids with yield at each sampling point in 2022.

		Weevil damage Assessment 1		Weevil damage Assessment 2		Bruchid damage		Aphid numbers	
		r2	*p* value	r2	*p* value	r2	*p* value	r2	*p* value
WW	Field 1	0.1678	**0.0468**	0.1504	0.0611	0.2801	**0.0078**	0.0136	0.5880
	Field 2	0.0872	0.1611	0.0433	0.3289	0.1139	0.1067	0.1314	0.0817
	Field 3	0.0005	0.9165	0.0215	0.4941	0.1209	0.0960	0.1024	0.1274
	Field 4	0.1780	**0.0400**	0.1043	0.1238	0.0416	0.3392	0.0716	0.3392
PAP	Trap crop field	0.0801	0.2403	0.3477	**0.0079**	0.0000	0.9988	0.0076	0.9988
	Control field	0.0007	0.9153	0.2688	**0.0229**	0.2970	**0.0158**	0.0056	0.7608

* Values highlighted in bold are statistically significant.

Percentage pea and bean weevil damage per plant was higher at PAP than at WW and aphid numbers per plant were substantially higher at PAP than WW. Bruchid beetle damage was higher at WW than PAP (Table 5).

Table 5. Mean percent damage to seed caused by bruchid beetles (by number of seeds), mean number of pea and bean weevil notches per plant and mean number of aphids per plant recorded in each field at WW and PAP in 2022, with a comparison between the early sown bean trap crop area and the main crop at WW.

	Mean % Bruchid damage		Mean no of pea and bean weevil notches per plant		Mean number of aphids per plant	
Site	Trap crop	Rest of the field	Trap crop	Rest of the field	Trap crop	Rest of the field
WW Field 1	44.9	19.3	31.3	19.2	0.1	1.3
WW Field 2	53.3	17.9	23.7	22.2	0	33.2
WW Field 3	45.4	23.8	22	22.6	1.6	22
WW Field 4	27.4	21.6	23.9	17	72.2	57.1
PAP Trap Crop Field		8.5		23.2		129.3
PAP Control Field		12.9		28.2		118.2

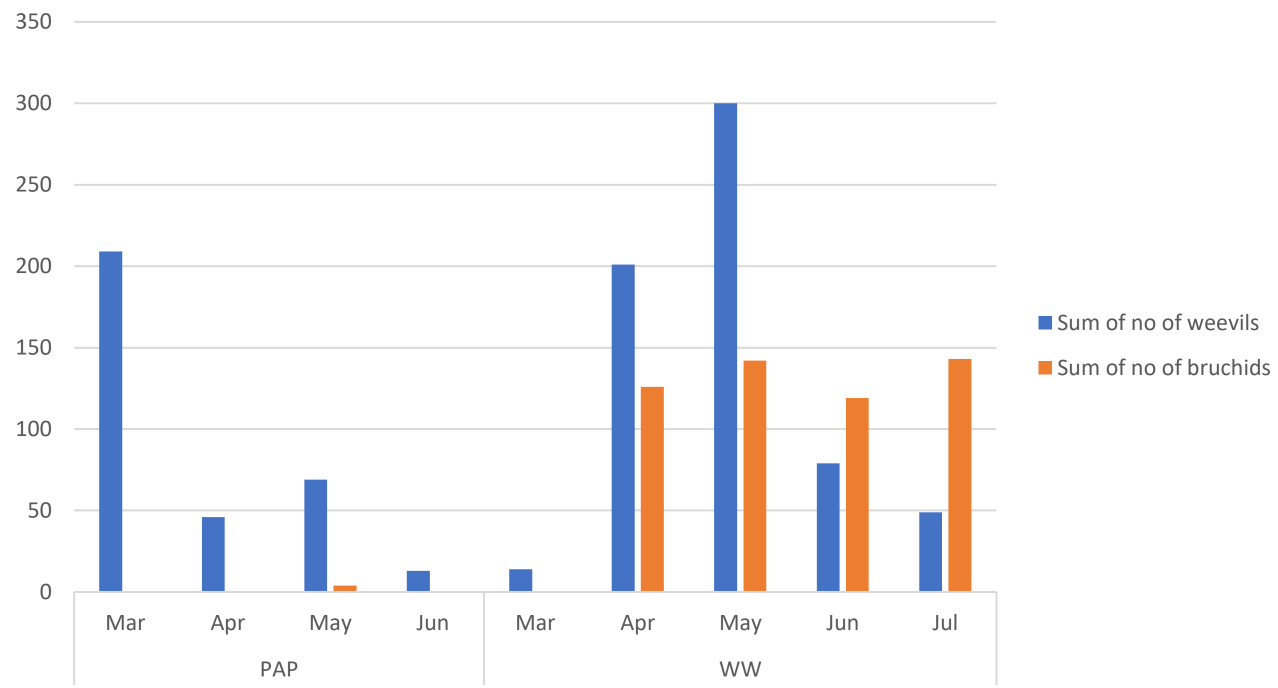


Figure 11. Total number of pea and bean weevils and bruchid beetles captured and removed from the trapping stations from both sites in 2022.

The most important factor associated with yield at WW was plant establishment (Table 6). This was also true for the trap crop field at PAP, but not for the control field.

Table 6. Regression analysis for all sites, comparing plant establishment with yield at each sampling point in 2022.

		Plant counts	
		r2	*p* value
WW	Field 1	0.7171	**1.8179E-07**
	Field 2	0.9779	**1.0457E-19**
	Field 3	0.9861	**6.5847E-22**
	Field 4	0.7228	**1.4456E-07**
PAP	Trap crop field	0.3860	**0.0045**
	Control field	0.0080	0.7159

* Values highlighted in bold are statistically significant.

Site WW 2022.

Pest damage	0-10	10.01-20	20.01-30	30.01-40	40.01-50	>50

Figure 12. Key for pest damage heat maps in Figures 13 to 24 and 30-33.

The heat maps below provide a representation of the level of damage at each sampling point per field.

There was a trend at WW that indicated higher levels of pea and bean weevil damage closer to the trap crop or field edge at the first assessment on 25th April, although this was less clear in field 4 which had no trap crop (Figures 13 to 16).

Weevil damage on 25th of April 2022

5	4.9	5.2	7.6	8.2	11.1
4	8.4	9.0	10.4	9.9	11.2
3	12.5	14.8	14.8	15.4	20.4
2	23.7	24.4	26.7	27.8	27.6
Trap Crop 1	33.8	28.3	34.8	30.4	31.8
	A	B	C	D	E

Figure 13. Mean pea and bean weevil damage as notches per plant at each sample point on 25th of April 2022 at field 1 with trap crop and lures.

5	8.2	6.8	9.0	7.4	6.5
4	10.5	9.0	12.2	11.1	8.8
3	18.2	16.0	25.5	21.5	16.3
2	25.1	29.8	24.5	27.1	28.1
Trap Crop 1	30.3	36.0	31.5	35.1	30.4
	A	B	C	D	E

Figure 14. Mean pea and bean weevil damage as notches per plant at each sample point on 25th of April 2022 at field 2 with trap crop only.

5	7.8	28.8	6.9	6.0	8.8
4	10.7	6.8	9.5	10.9	13.1
3	20.5	9.8	24.0	21.2	30.5
2	31.8	20.3	30.4	27.3	22.7
Trap Crop 1	33.8	31.2	23.5	24.4	24.4
	A	B	C	D	E

Figure 15. Mean pea and bean weevil damage as notches per plant at each sample point on 25th of April 2022 at field 3 with trap crop only.

5	12.1	10.5	9.9	14.8	16.6
4	9.8	11.4	14.0	9.9	20.3
3	10.7	13.7	14.6	14.6	26.0
2	10.8	9.6	13.1	10.2	26.8
1	19.8	14.9	21.5	16.9	33.9
	A	B	C	D	E

Figure 16. Mean pea and bean weevil damage as notches per plant at each sample point on 25th of April 2022 at field 4 with no trap crop.

There was a trend at WW indicating higher levels of weevil damage closer to the trap crop or field edge at the second assessment on 10th May, and this was clearer in Field 1 which contained the lures (Figures 17 to 20).

Weevil damage on 10th of May 2022

5	5.3	6.4	8.1	10.8	11.5
4	10.2	10.5	13.9	12.8	15.5
3	23.0	19.4	27.6	27.3	25.9
2	29.6	29.1	34.2	32.6	31.0
Trap Crop 1	32.7	30.0	34.5	28.7	30.9
	A	B	C	D	E

Figure 17. Mean pea and bean weevil damage as notches per plant at each sample point on 10th of May 2022 at field 1 with trap crop and lures.

5	14.3	14.6	15.2	13.6	12.7
4	15.9	16.0	19.9	20.1	18.3
3	26.2	29.3	22.6	27.2	25.3
2	26.2	31.0	32.1	34.6	29.6
Trap Crop 1	27.4	20.7	27.4	20.6	22.6
	A	B	C	D	E

Figure 18. Mean pea and bean weevil damage as notches per plant at each sample point on 10th of May 2022 at field 2 with trap crop only.

5	16.7	14.6	15.3	13.3	12.1
4	21.3	18.9	18.5	19.2	14.9
3	31.4	29.2	26.3	27.6	22.7
2	28.4	32.5	33.0	25.5	31.6
Trap Crop 1	21.7	22.5	15.6	23.0	27.2
	A	B	C	D	E

Figure 19. Mean pea and bean weevil damage as notches per plant at each sample point on 10th of May 2022 at field 3 with trap crop only.

	A	B	C	D	E
5	13.1	11.3	10.8	18.6	19.4
4	10.6	11.4	15.1	15.1	19.1
3	10.7	15.7	16.4	18.4	22.3
2	9.6	10.3	13.8	20.9	22.1
1	24.6	21.9	25.8	22.5	24.9

Figure 20. Mean pea and bean weevil damage as notches per plant at each sample point on 10th of May 2022 at field 4 with no trap crop.

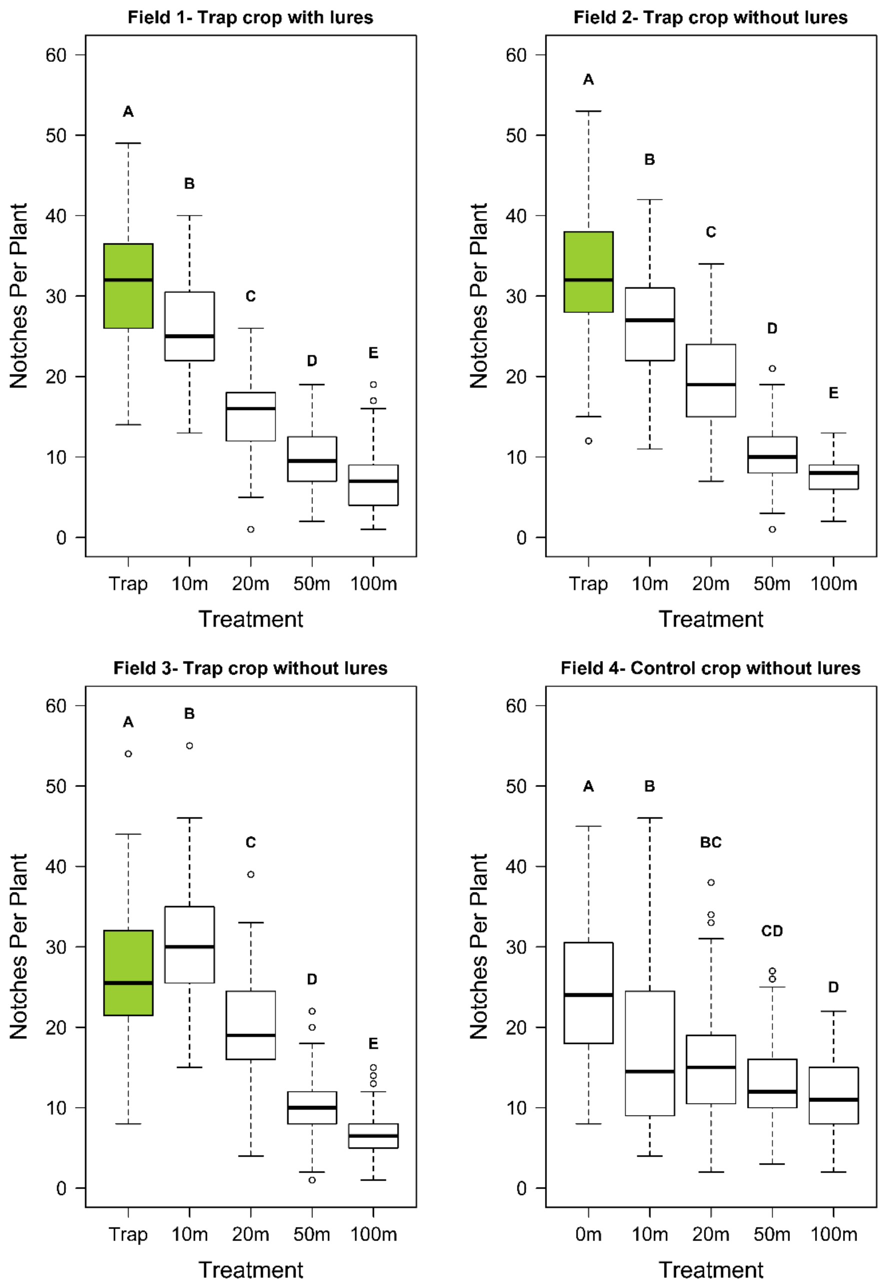


Figure 21. Mean number of weevil notches per plant at sampling points within the trap crop and at 10,20, 50 and 100 metres distance from the trap crop for all fields at WW on 25th April 2022.

Field 1 trap crop had the highest level of damage compared to all other fields. In field 4 where there was no trap crop, only the sample point in the headland was significantly different from the rest of the field (Figure 22).

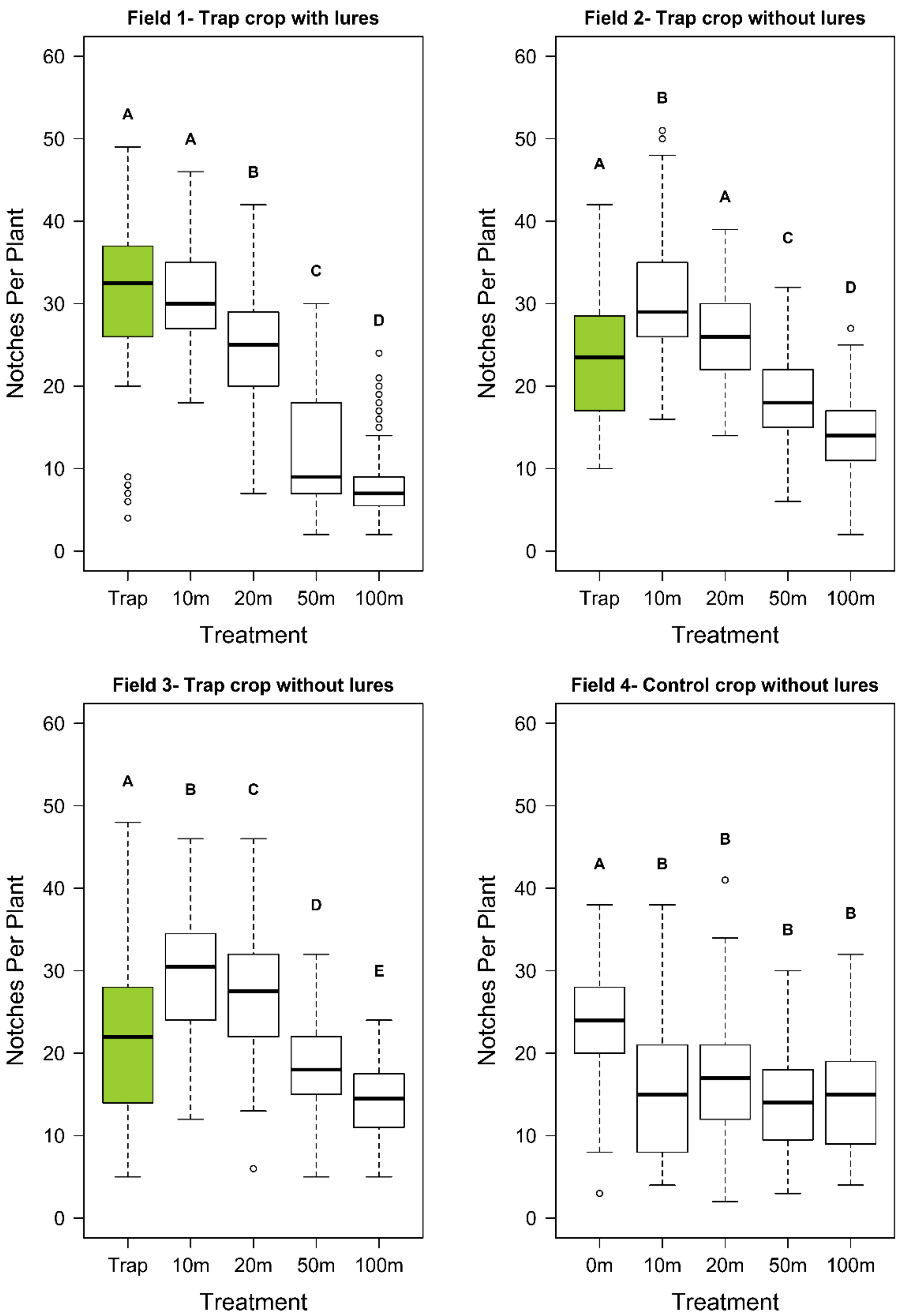


Figure 22. Mean number of weevil notches at sampling points within the trap crop and at 10,20, 50 and 100 metres distance from the trap crop for all fields at WW on 10th May 2022.

Bruchid beetle damage 2022

Bruchid beetle damage levels were higher in the trap crop areas at WW, although there was no consistent pattern in the main crop (Figures 23 to 26). Bruchid beetle damage at the field edge in field 4 was not clearly higher than in the main crop (Figure 26).

	A	B	C	D	E
5	19.5	16.8	9.5	9.5	37.7
4	8.3	27.2	16.5	8.0	23.0
3	25.5	33.0	21.8	15.7	13.8
2	21.7	53.2	15.2	5.1	5.0
Trap Crop 1	62.0	51.7	26.8	42.7	40.4

Figure 23. Mean percentage seeds damaged by bruchid beetle at each sampling point at field 1 with trap crop and lures.

	A	B	C	D	E
5	30.1	22.0	14.5	20.3	13.1
4	30.2	14.1	10.0	8.1	3.5
3	11.2	9.7	18.1	23.5	26.3
2	18.5	27.8	19.0	11.8	26.1
Trap Crop 1	54.6	63.4	73.2	31.7	43.4

Figure 24. Mean percentage seeds damaged by bruchid beetle at each sampling point at field 2 with trap crop only.

	A	B	C	D	E
5	22.2	14.7	29.1	19.6	35.6
4	10.9	15.6	12.0	27.9	27.2
3	16.5	36.4	23.7	11.6	21.7
2	26.1	29.4	47.1	20.0	29.5
Trap Crop 1	44.4	40.6	54.5	41.7	45.7

Figure 25. Mean percentage seeds damaged by bruchid beetle at each sampling point at field 3 with trap crop only.

	A	B	C	D	E
5	28.1	28.6	18.2	15.5	13.5
4	9.7	10.0	17.4	14.4	14.7
3	41.1	5.7	24.9	33.0	19.0
2	14.0	10.4	32.0	26.4	26.4
1	29.4	22.2	28.6	17.1	39.7

Figure 26. Mean percentage seeds damaged by bruchid beetle at each sampling point at field 4 with no trap crop.

Plant population 2022

Plant density						
	0-10	10.01-20	20.01-30	30.01-40	40.01-50	50.01-60
	60.01-70	70.01-80	80.01-90	90.01-100	>100.01	

Figure 27. Key for plant population heat maps in Figures 28 to 31. Target plant population for spring beans is 45-55 plants per square metre.

Plant density was higher than expected at WW (Figures 28 to 31). Spring bean plant density normally targets 45 to 50 plants per square metre.

5	67	77	70	76	76
4	85	63	69	72	77
3	67	71	56	75	67
2	57	67	69	73	78
Trap Crop 1	56	59	59	63	60
	A	B	C	D	E

Figure 28. Mean plants per m^2 at each sampling point at field 1 with trap crop and lures.

5	68	64	64	69	75
4	60	53	65	49	55
3	63	48	69	64	47
2	93	56	53	60	52
Trap Crop 1	41	40	52	50	40
	A	B	C	D	E

Figure 29. Mean plants per m^2 at each sampling point at field 2 with trap crop only.

5	72	65	54	68	55
4	65	59	51	68	67
3	45	49	56	60	72
2	46	62	65	90	52
Trap Crop 1	47	46	46	50	53
	A	B	C	D	E

Figure 30. Mean plants per m^2 at each sampling point at field 3 with trap crop only.

5	73	75	59	63	78
4	71	78	58	56	55
3	52	48	65	63	46
2	118	65	80	56	55
1	43	61	66	52	46
	A	B	C	D	E

Figure 31. Mean plants per m^2 at each sampling point at field 4 with no trap crop.

Aphid population 2022.

Numbers of aphids recorded in the field without the trap crop (Figure 35) was higher closer to the edge of the field. In field 3 the damage in the main crop was more severe than the damage in the trap crop. Overall, the level of damage in the trap crop in fields 1 and 2 was very low. There were no clear trends in aphid population across the fields at WW (Figures 32 to 35).

5	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0
3	6.1	0.0	0.0	0.0	2.5
2	0.0	15.0	0.0	2.5	0.0
Trap Crop 1	0.5	0.0	0.0	0.0	0.0
	A	B	C	D	E

Figure 32. Mean number of aphids per plant at each sampling point at field 1 with trap crop and lures.

5	152.5	27.3	50.0	70.0	87.6
4	53.5	17.5	40.0	27.8	2.8
3	11.3	0.3	55.1	0.0	0.0
2	2.6	5.0	52.6	0.5	8.8
Trap Crop 1	0.0	0.0	0.0	0.0	0.0
	A	B	C	D	E

Figure 33. Mean number of aphids per plant at each sampling point at field 2 with trap crop only.

5	0.0	32.5	1.3	6.3	40.0
4	35.0	15.0	50.0	40.3	15.0
3	95.0	25.3	12.6	0.0	0.0
2	62.5	10.4	0.0	0.0	0.0
Trap Crop 1	0.0	0.0	0.5	0.0	7.5
	A	B	C	D	E

Figure 34. Mean number of aphids at each sampling point at field 3 with trap crop only.

5	0.8	27.1	144.7	7.9	194.7
4	52.4	0.4	130.6	2.6	115.8
3	1.6	221.8	73.8	55.6	57.1
2	11.5	14.2	0.0	21.1	9.2
1	85.7	84.3	91.6	69.7	34.7
	A	B	C	D	E

Figure 35. Mean number of aphids at each sampling point at field 4 with no trap crop.

Table 7. Summary of ANOVA statistical analysis for all assessment data between fields at WW in 2022.

WW	*p*-value
Yield	**0.00598361**
Mean bruchid damage	0.439255701
Mean number of weevil notches atT1	0.364531577
Mean number of weevil notches at T2	**0.022062793**
Mean number of aphids	**4.12839E-06**

* Values highlighted in bold are statistically significant.

Yield in field 1 was significantly higher than yield in fields 2 and 3, but not field 4 (Figure 36).

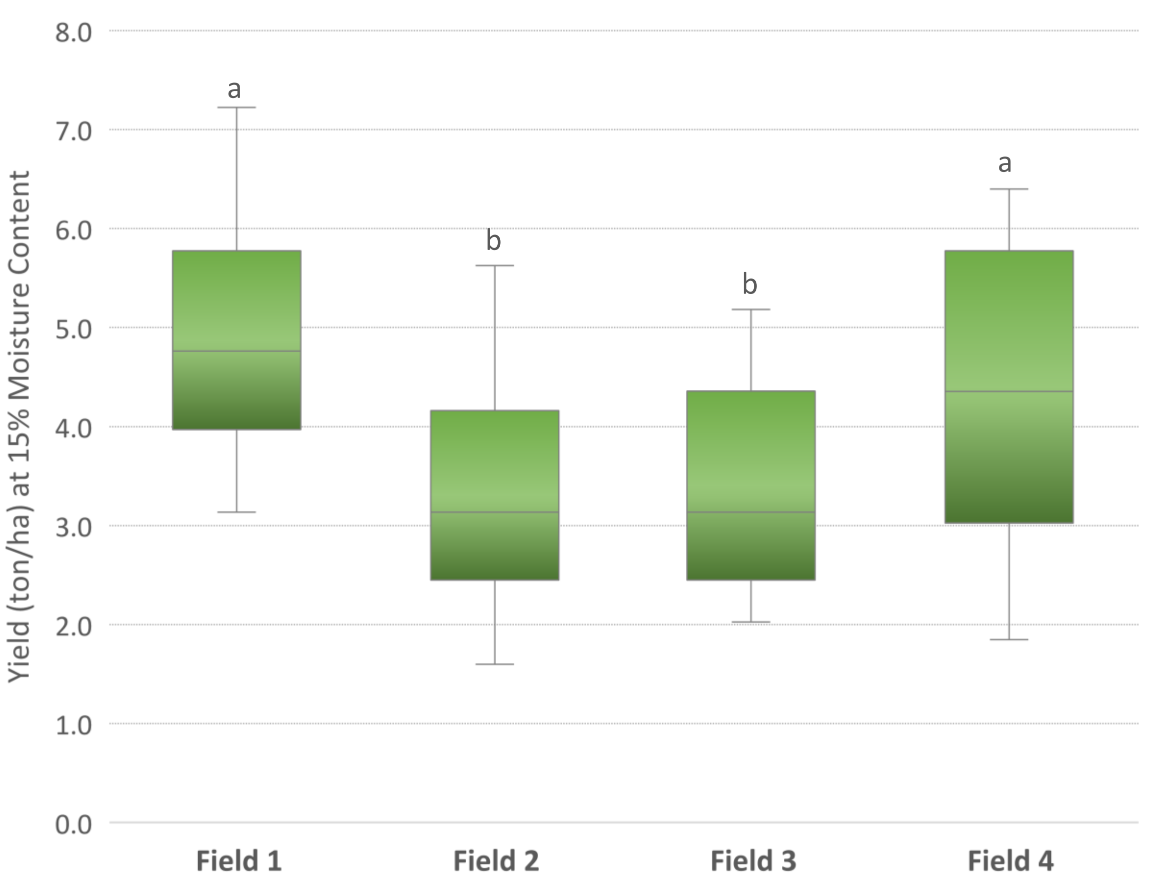


Figure 36. Mean yield in all fields at WW in 2022.

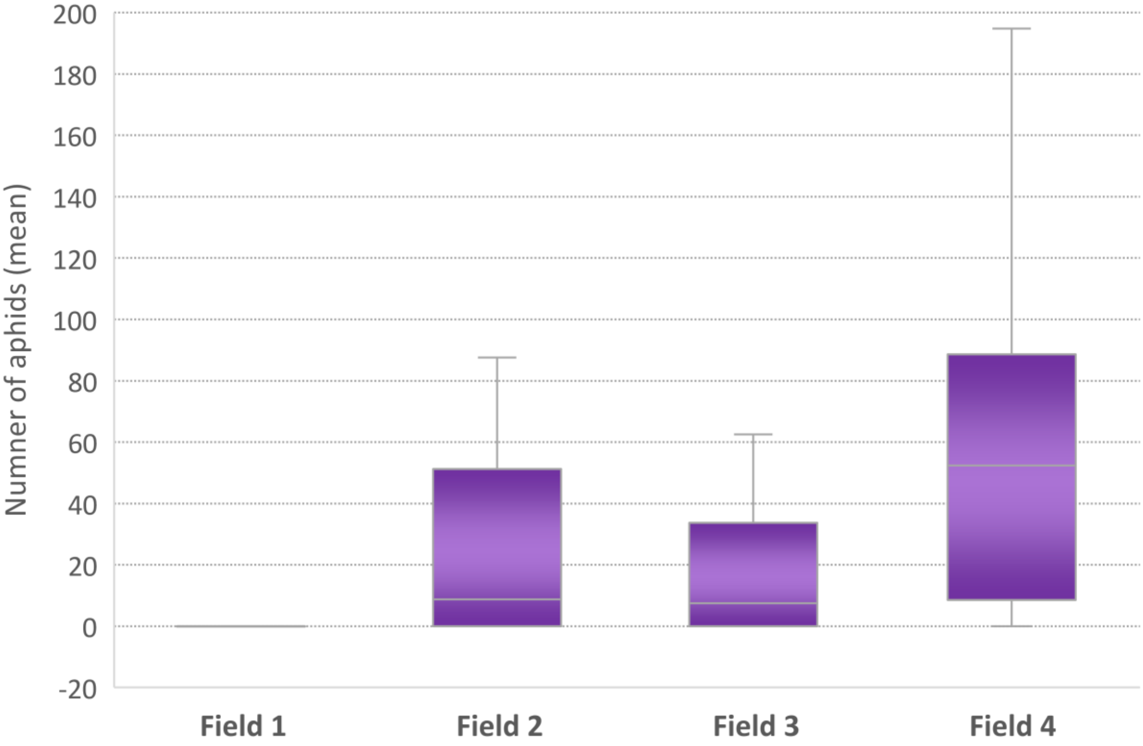


Figure 37. Mean number of weevil notches in all fields at WW in 2022.

There were no significant differences in weevil damage between fields at WW in 2022 (Figure 37).

Mean number of aphids in field 4 was significantly higher than in the other fields (Figure 38).

b

a

a

a

Figure 38. Mean number of aphids in all fields at WW in 2022.

Site PAP 2022

Pest damage	0-10	10.01-20	20.01-30	30.01-40	40.01-50	>50

Figure 39. Key for pest damage heat maps in Figures 40-45.

Weevil damage 13th of May 2022

There were no clear patterns or differences in the level of pea and bean weevil damage across or between fields at PAP in 2022 (Figures 40 to 43).

5	20.3	21.4	22.5	14.5	11.3
4	24.0	22.9	23.1	22.9	13.5
3	19.0	23.1	17.7	20.6	21.6
2	23.7	16.3	14.7	19.8	18.6
	A	B	C	D	E

Figure 40. Mean pea and bean weevil damage as notches per plant at each sampling point in the trap crop field on 13th May 2022.

5	28.5	22.3	26.5	22.6	22.4
4	25.8	27.6	28.6	20.5	21.0
3	19.8	23.1	27.0	25.2	25.0
2	19.8	24.0	24.3	21.4	24.9
	A	B	C	D	E

Figure 41. Mean pea and bean weevil damage as notches per plant at each sampling point in the control field on 13th May 2022.

Weevil damage 25th May 2022

5	33.6	30.5	30.5	25.2	19.4
4	28.1	30.3	30.4	26.2	19.7
3	26.8	30.0	25.4	25.4	26.4
2	28.6	23.7	26.6	26.2	23.4
	A	B	C	D	E

Figure 42. Mean pea and bean weevil damage as notches per plant at each sampling point in the trap crop field on 25th May 2022.

5	28.5	31.4	31.4	30.4	35.5
4	31.8	33.3	35.8	33.9	30.8
3	30.0	29.1	32.2	35.5	38.0
2	29.4	30.7	33.0	34.3	35.3
	A	B	C	D	E

Figure 43. Mean pea and bean weevil damage as notches per plant at each sampling point in the control field on 25th May 2022.

Bruchid beetle damage

There were no clear patterns or differences across or between fields in the level of bruchid damage at PAP in 2022 (Figures 44 to 45)

5	6.6	8.2	2.6	11.7	3.3
4	4.3	8.2	2.9	6.1	2.5
3	26.3	5.0	11.5	4.0	4.5
2	6.3	17.6	18.3	7.2	13.3
	A	B	C	D	E

Figure 44. Mean bruchid beetle damage as percentage number of seeds damaged at each sample point at PAP in the trap crop field 2022.

Cells in grey (Figure 45) represent areas in the field where, due to poor establishment and heavy bird pressure, it was not possible to determine yield or bruchid beetle damage.

5	22.1	46.0	0.0	0.0	0.0
4	9.1	7.9	10.0	0.0	0.0
3	17.9	18.5	1.3	0.0	0.0
2	11.0	11.7	0.0	0.0	0.0
	A	B	C	D	E

Figure 45. Mean bruchid beetle damage as percentage number of seeds damaged at each sample point at the PAP control field 2022.

Plant population 2022

There were no clear differences in plant density at the different sampling points, and plant density was very low. The normal target plant density for spring beans is 45 to 50 plants per square metre.

Plant density	**0-10**	**10.01-20**	**20.01-30**	**30.01-40**	**40.01-50**	**50.01-60**
	60.01-70	**70.01-80**	**80.01-90**	**90.01-100**	**>100.01**	

Figure 46. Key for plant population heat maps in Figures 47 and 48. Target plant population for spring beans is 45-55 plants per square metre.

5	12	8	5.6	4	4.8
4	10.4	4.8	4.8	7.2	3.2
3	8.8	5.6	11.2	2.4	5.6
2	7.2	11.2	12	3.2	2.4
	A	B	C	D	E

Figure 47. Mean plants per square metre at each sampling point at PAP trap crop field.

5	8.8	17.6	4	20	4.8
4	12	10.4	11.2	22.4	5.6
3	13.6	9.6	16	9.6	11.2
2	17	16	16.8	31.2	7.2
	A	B	C	D	E

Figure 48. Mean plants per square metre at each sampling point at PAP control field.

Aphid populations 2022

The number of aphids recorded at each sampling point was very high at PAP in 2022 (Figures 49 and 50). This may have been due to the low plant density leading to higher numbers of aphids per plant.

5	25.0	25.0	37.3	42.5	10.0
4	25.5	60.0	50.0	26.3	85.0
3	212.5	161.2	196.3	76.3	400.2
2	721.3	118.4	227.5	31.3	55.5
	A	B	C	D	E

Figure 49. Mean number of aphids per plant at each sample point at PAP trap crop field in 2022.

5	209.0	78.0	80.0	2.0	10.0
4	52.0	79.0	107.0	12.0	41.0
3	130.0	196.0	215.0	182.0	151.0
2	161.0	156.0	202.0	118.0	183.0
	A	B	C	D	E

Figure 50. Mean number of aphids per plant at each sample point at PAP control crop field in 2022.

T test analysis - PAP

There was a significant difference in the level of weevil damage between the trap crop field and the control field at both assessment dates at PAP in 2022. Weevil damage was higher in the control field on 25th April, but higher in the trap crop field on 10th May (Tables 8 and 9).

Table 8. T-test statistics for PAP, comparing weevil damage between the trap crop field and control field 2022 on 25th April 2022.

	Trap crop field	Control field
Mean	19.55	23.9925
Variance	14.2508	7.7895
Observations	20	20
Pooled Variance	11.0202	
Hypothesized Mean Difference	0	
df	38	
t Stat	-4.2319	
P(T<=t) one-tail	**7.05435E-05**	

* Values highlighted in bold are statistically significant.

Table 9. T-test statistics for PAP, comparing weevil damage in the crops between the trap crop field and control field 2022 on 10th May 2022.

	Trap crop field	Control field
Mean	26.7925	32.49
Variance	13.0767	6.813
Observations	20	20
Pooled Variance	9.9447	
Hypothesized Mean Difference	0	
df	38	
t Stat	-5.7133	
P(T<=t) one-tail	**7.041E-07**	

* Values highlighted in bold are statistically significant.

The number of aphids recorded at 10m and 20m distance from the trap crop at PAP was significantly higher than those recorded at 50m and 100m distance from the trap crop (Figure 51).

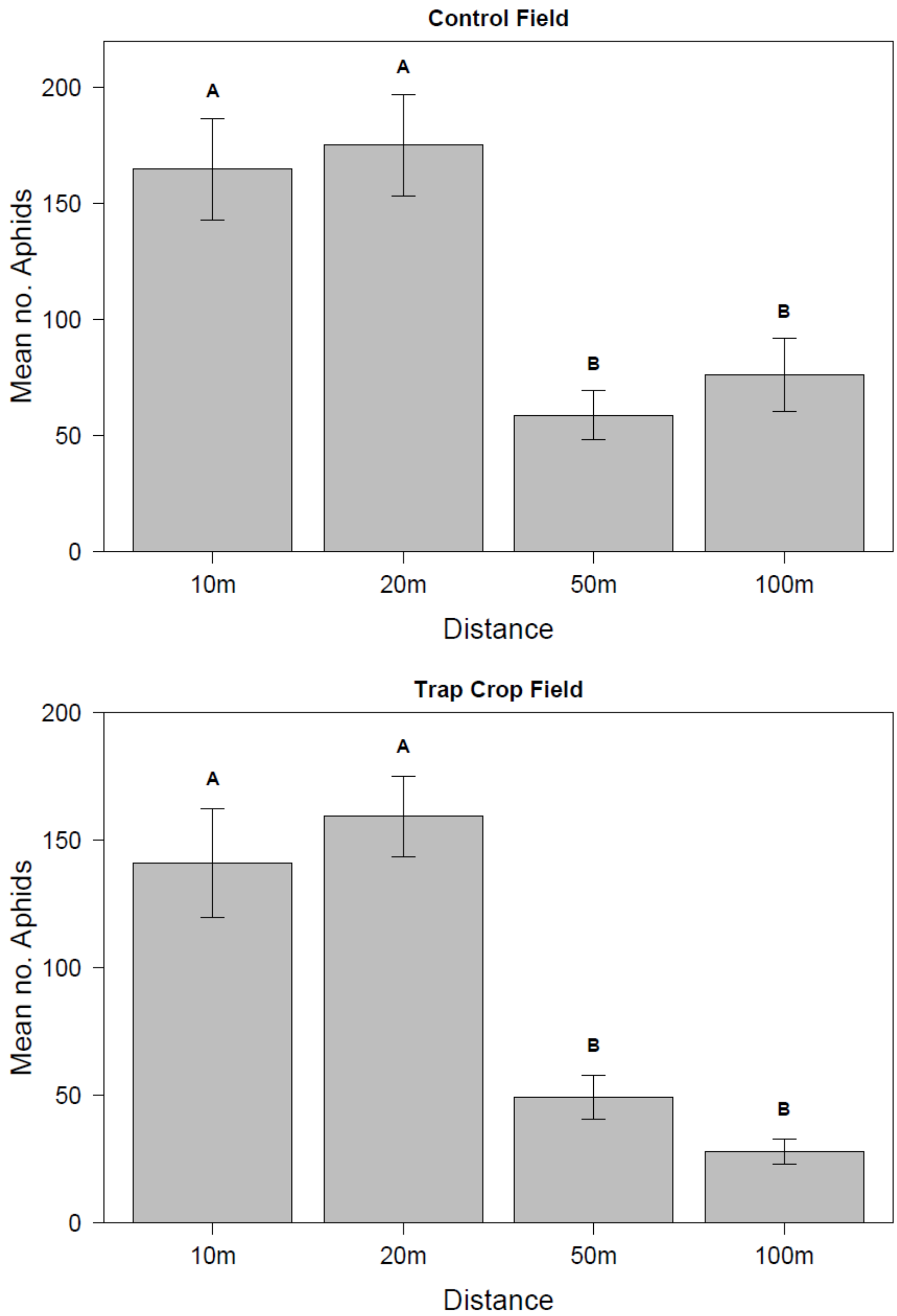


Figure 51. Mean number of aphids recorded in the main crops in the control field and trap crop field at PAP, at 10m, 20m, 50m and 100m distance from either the edge of the field in the control crop, or the trap crop in the trap crop field.

Biodiversity monitoring

Site WW 2022.

Table 10. Total number of insects recorded in all pitfall traps in May and June 2022 at WW in all fields.

Species	Common name	23-May	10-Jun	23-Jun
Amara spp.	sun beetle	376	209	26
Order Coleoptera	beetle	39	94	16
Family Carabidae	ground beetle	65	132	31
Nicrophorus spp.	sexton beetle	0	5	0
Family Staphylinidae	rove beetle	18	54	31
Bruchus rufimanus	bruchid beetle	2	1	0
Sitona lineatus	pea and bean weevil	3	2	0
Aphis spp.	aphid	1	1	9
Meligethes aeneus	pollen beetle	131	259	41
Oulema melanopa	cereal leaf beetle	0	3	0
Order Diptera (other)	other flies	16	13	9
Order Diptera	true flies	212	94	69
Order Araneae	spiders	18	33	58
Opiliones spp.	harvestman	0	2	0
Class Chilopoda	centipede	0	0	1
Armadillidium vulgare	woodlouse	0	0	1
Tipula spp.	crane fly	6	0	0

* Where identification to species was not possible, insects were identified to order, family or genus.

Figure 52. Simpson Index calculated using all pitfall trap records at WW for the trap crop area, and at 50m and 100m distance from the trap crop.

Higher diversity of insects was recorded in the trap crops at WW using the pitfall traps, than in the main crop (Figure 52).

Table 11. Total number of insects recorded in all sweep net samples in June and July 2022 in field 1 at WW.

Species	Common name	10-Jun	23-Jun	07-Jul
Family Aphididae	aphids (green)	30	59	1
Myzus persicae	peach potato aphid	4	0	0
Aphis fabae	black bean aphid	0	8	0
Order Diptera	larger true flies	26	17	22
Order Diptera	midges	14	0	41
Bruchus rufimanus	Bruchid beetle	1	10	1
Meligethes spp.	pollen beetles	1	3	1
Sitona lineatus	pea and bean weevil	30	11	106
Lygus rugulipennis	tarnished plant bug	0	0	1
Tipula spp.	cranefly	0	0	1
Family Cantharidae	soldier beetle	1	2	3
Coccinella spp.	ladybird	0	2	1
Chrysoperla carnea	lacewing	0	6	2
Bombus spp.	bumblebees	2	0	0
Suborder Aprocrita	parasitic wasps	2	8	13
Forficula auricularia	earwig	0	0	1
Order Araneae	spiders	2	0	14
Order Coleoptera	small black beetle	2	0	0
Family Curculionidae	other weevils	0	0	2
Family Cicadellidae	leafhoppers	8	7	20
Myrmica rubra	red ants	0	6	0

* Where identification to species was not possible, insects were identified to order, family or genus.

Table 12. Total number of insects recorded in all sweep net samples in June and July 2022 in field 2 at WW.

Species	Common name	10-Jun	23-Jun	07-Jul
Family Aphididae	aphids (green)	22	65	2
Myzus persicae	peach potato aphid	4	4	0
Aphis fabae	black bean aphid	1	9	0
Order Diptera	larger true flies	18	39	13
Order Diptera	midges	13	0	49
Order Lepidoptera	other caterpillar	1	0	0
Bruchus rufimanus	bruchid beetle	6	5	4
Meligethes spp.	pollen beetles	0	6	0
Sitona lineatus	pea and bean weevil	44	17	74
Lygus rugulipennis	tarnished plant bug	0	0	1
Family Cantharidae	soldier beetle	3	1	4
Coccinella spp.	ladybird	0	3	2
Chrysoperla carnea	lacewing	0	0	1
Apis mellifera	honeybee	1	0	0
Suborder Aprocrita	parasitic wasps	0	4	5
Order Araneae	spiders	1	7	6
Order Coleoptera	small black beetle	1	0	0
Order Diptera	other flies	0	10	0
Family Curculionidae	other weevils	2	0	1
Family Cicadellidae	leafhoppers	2	6	24
Order Lepidoptera	moth	0	0	1

* Where identification to species was not possible, insects were identified to order, family or genus.

Table 13. Total number of insects recorded in all sweep net samples in June and July 2022 in field 3 at WW.

Species	Common name	10-Jun	23-Jun	07-Jul
Family Aphididae	aphids (green)	14	77	0
Myzus persicae	peach potato aphid	1	2	0
Aphis fabae	black bean aphid	5	7	0
Order Diptera	larger true flies	10	69	34
Order Diptera	midges	11	0	39
Order Lepidoptera	other caterpillar	0	0	1
Bruchus rufimanus	bruchid beetle	4	3	2
Meligethes spp.	pollen beetles	5	0	0
Sitona lineatus	pea and bean weevil	16	37	105
Lygus rugulipennis	tarnished plant bug	0	0	1
Tipula spp.	cranefly	1	0	0
Family Cantharidae	soldier beetle	0	3	1
Coccinella spp.	ladybird	0	3	1
Chrysoperla carnea	lacewing	0	0	3
Suborder Aprocrita	parasitic wasps	1	5	5
Order Araneae	spiders	1	3	4
Family Curculionidae	other weevils	0	1	0
Family Cicadellidae	leafhoppers	1	9	7

* Where identification to species was not possible, insects were identified to order, family or genus.

Table 14. Total number of insects recorded in all sweep net samples in June and July 2022 in field 4 at WW.

Species	Common name	10-Jun	23-Jun	07-Jul
Family Aphididae	aphids (green)	6	11	0
Myzus persicae	peach potato aphid	2	0	0
Aphis fabae	black bean aphid	3	150	0
Order Diptera	larger true flies	16	16	8
Order Diptera	midges	19	0	10
Bruchus rufimanus	bruchid beetle	1	26	2
Meligethes spp.	pollen beetles	12	3	0
Sitona lineatus	pea and bean weevil	32	14	1
Lygus rugulipennis	tarnished plant bug	0	1	0
Syrphus spp.	hoverfly	0	1	0
Tipula spp.	cranefly	0	4	0
Family Cantharidae	soldier beetle	0	7	0
Coccinella spp.	ladybird	2	29	3
Chrysoperla carnea	lacewing	0	2	1
Pimpla rufipes	black slip wasp	0	1	0
Suborder Aprocrita	parasitic wasps	5	7	2
Order Araneae	spiders	1	0	6
Family Curculionidae	other weevils	1	0	1
Family Cicadellidae	leafhoppers	2	10	9

* Where identification to species was not possible, insects were identified to order, family or genus.

Insect populations in the trap crop areas of fields 1 and 2 at WW were less diverse than at 100m distance into the crop. In fields 3 and 4 greater insect diversity was recorded in the trap crop area (Figure 53).

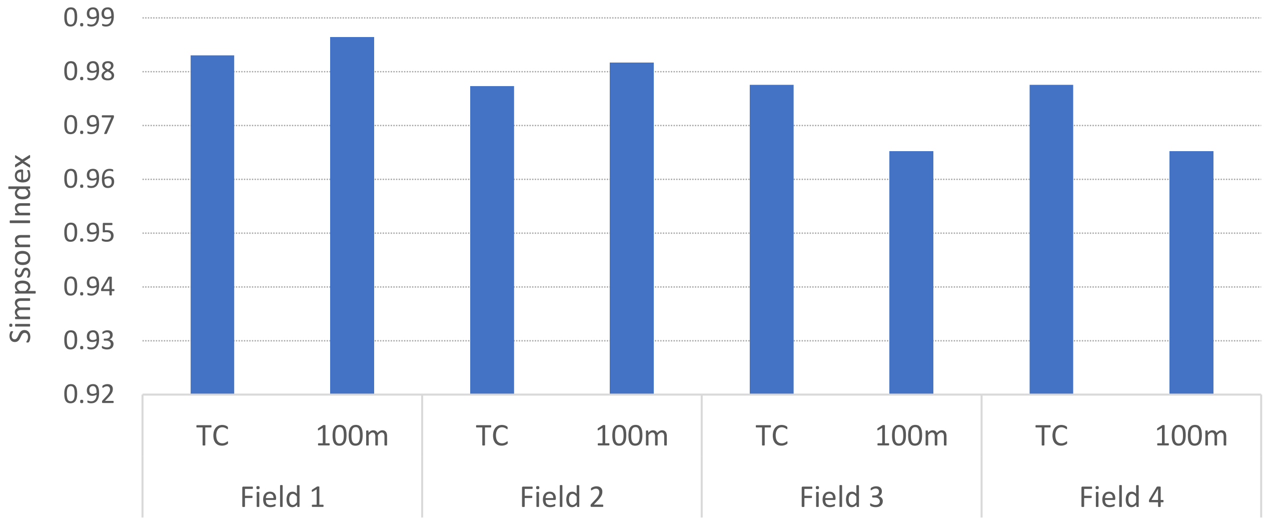


Figure 53. Simpson Index calculated from all sweep netting records at WW for trap crop area and at 100m distance from the trap crop.

Site PAP 2022.

Table 15. Total number of insects recorded in all pitfall traps in May and June 2022 in the trap crop field and control field at PAP.

Species	**Common name**	**24-May**	**10-Jun**	**24-Jun**
Amara spp.	sun beetle	40	78	57
Order Coleoptera	beetle	31	83	10
Family Carabidae	ground beetle	14	121	47
Family Staphylinidae	rove beetle	0	11	9
Colembola spp.	springtail	0	0	5
Sitona lineatus	pea and bean weevil	2	0	0
Meligethes aeneus	pollen beetle	1	3	1
Deroceras reticulatum	slugs	12	13	2
Helicidae spp.	snail	0	3	3
Gryllus spp.	cricket	0	0	1
Order Diptera	other flies	19	45	35
Order Araneae	spiders	13	39	28
Opiliones spp.	harvestman	82	21	28
Class Chilopoda	centipede	0	4	0
Armadillidium vulgare	woodlouse	3	6	1
Myrmica spp.	red ants	4	5	0
Coccinella spp.	ladybird	0	2	3
Forficula auricularia	earwig	0	1	0

* Where identification to species was not possible, insects were identified to order, family or genus.

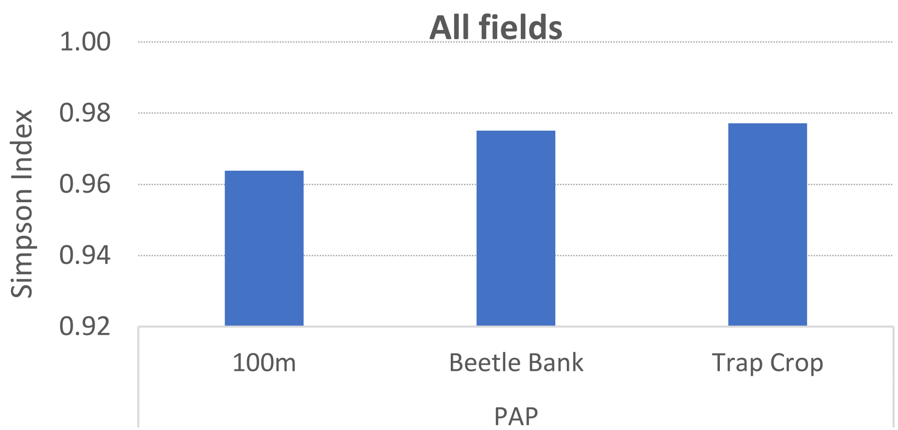


Figure 54. Simpson Index calculated for all fields at PAP site, for the trap crop area, 100m into the crop and the beetle bank using data collected from the pitfall traps.

Table 16. Total number of insects recorded in sweep net sampling in June and July 2022 at PAP Trap crop field.

Species	Common name	24-Jun	08-Jul	18-Jul
Aphis fabae	black bean aphid	12	59	3
Order Diptera	larger true flies	9	23	70
Order Diptera	midges	0	0	76
Lygocoris pabulinus	green capsid	6	3	0
Phyllotreta nemorum	turnip flea beetle	1	1	0
Bruchus rufimanus	bruchid beetle	0	1	0
Meligethes spp.	pollen beetles	74	49	17
Sitona lineatus	pea and bean weevil	2	9	65
Ceutorhynchus pallidactylus	cabbage stem weevil	0	4	0
Lygus rugulipennis	tarnished plant bug	0	0	5
Syrphus spp.	hoverfly	0	0	2
Tipula spp.	cranefly	18	5	0
Dermanyssus gallinae	red mites	0	0	2
Order Orthoptera	cricket	1	0	0
Order Orthoptera	grasshopper	0	0	1
Helicidae spp.	snail	2	2	0
Rhabdomiris spp.	capsid bug	4	4	0
Family Cantharidae	soldier beetle	3	16	1
Oedemera spp.	false blister beetle	0	0	1
Coccinella spp.	ladybird	3	19	7
Chrysoperla carnea	lacewing	0	0	1
Apis mellifera	honeybee	0	4	1
Suborder Aprocrita	parasitic wasps	34	19	5
Order Hymenoptera	other vespids	0	0	11
Forficula auricularia	earwig	0	0	1
Enallagma spp.	damselfly brown	0	0	2
Order Araneae	spiders	1	1	8
Leiobunum rotundum	harvestman	0	1	1

Species	Common name	24-Jun	08-Jul	18-Jul
Family Asilidae	robber fly	0	1	0
Order Diptera	other flies	2	13	0
Family Curculionidae	other weevils	9	2	10
Family Cicadellidae	leafhoppers	6	16	60
Order Lepidoptera	moth	0	0	1
Family Culicidae	mosquito	0	0	2

* Where identification to species was not possible, insects were identified to order, family or genus.

Table 17. Total number of insects recorded in sweep net sampling in June and July 2022 at PAP Control field.

Species	Common name	24-Jun	08-Jul	18-Jul
Family Aphididae	aphids (green)	5	0	0
Aphis fabae	black bean aphid	4	0	3
Order Diptera	larger true flies	32	20	66
Order Diptera	midges	28	0	0
Order Lepidoptera	other caterpillar	5	5	1
Lygocoris pabulinus	green capsid	0	7	5
Phyllotreta nemorum	turnip flea beetle	0	1	3
Meligethes spp.	pollen beetles	105	41	5
Sitona lineatus	pea and bean weevil	0	4	47
Ceutorhynchus pallidactylus	cabbage stem weevil	0	3	1
Lygus rugulipennis	tarnished plant bug	1	0	0
Syrphus spp.	hoverfly	6	0	0
Tipula spp.	cranefly	17	9	8
Dermanyssus gallinae	red mites	22	0	0
Order Orthoptera	cricket	0	1	0
Rhabdomiris spp.	capsid bug	3	1	0
Tyria jacobaeae	cinnabar moth caterpillar	0	0	2
Family Cantharidae	soldier beetle	5	3	0
Oedemera spp.	false blister beetle	6	0	0
Family Carabidae	ground beetle	0	1	0
Coccinella spp.	ladybird	1	5	4
Chrysoperla carnea	lacewing	3	0	0
Suborder Aprocrita	parasitic wasps	3	30	24
Enallagma spp.	damselfly brown	2	4	8
Order Araneae	spiders	6	4	1
Leiobunum rotundum	harvestman	4	1	3
Triplax aenea	triplax beetle	3	7	14
Order Coleoptera	small black beetle	10	0	0
Order Diptera	other flies	0	18	0
Family Cicadellidae	leafhoppers	72	39	30
Order Lepidoptera	moth	6	0	1

* Where identification to species was not possible, insects were identified to order, family or genus.

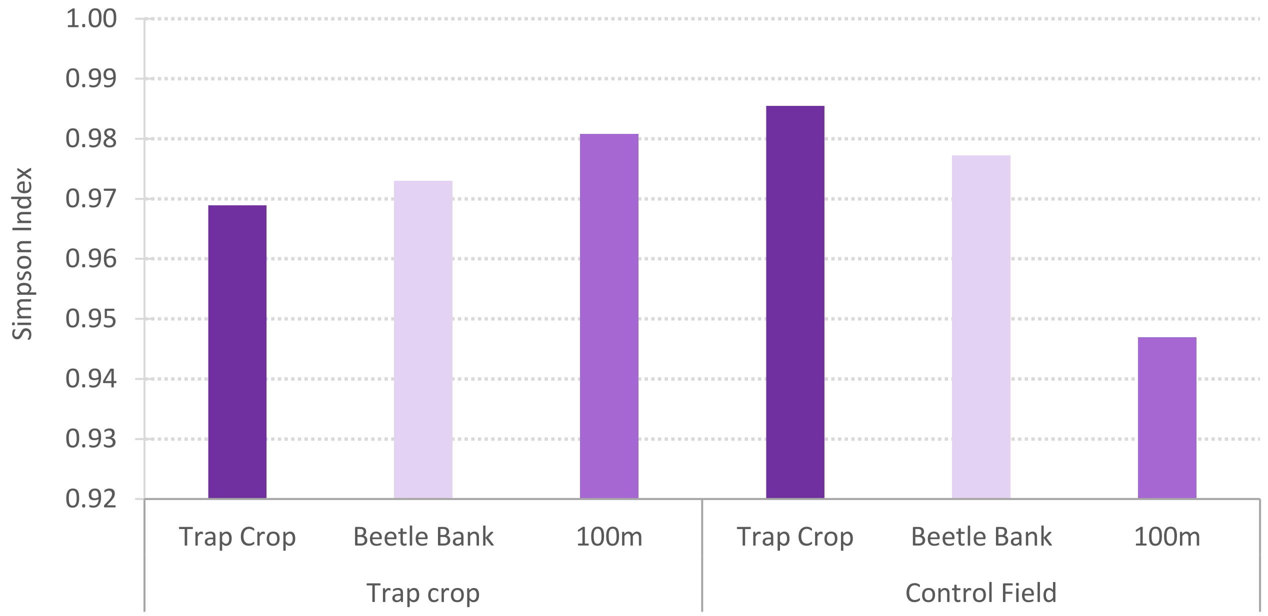


Figure 55. Simpson Index from sweep netting records in all fields at PAP comparing the biodiversity of the trap crop with 100m into the crop, and alongside the beetle bank.

Proportion of pests, beneficial and other insects at WW and PAP in 2022.

When the proportion of pest insect species recorded during sweep netting was compared to the proportion of beneficial and other insects at each site, there appeared to be some differences between the sites (Figure 56). This was also true of pitfall trap records (Figure 57).

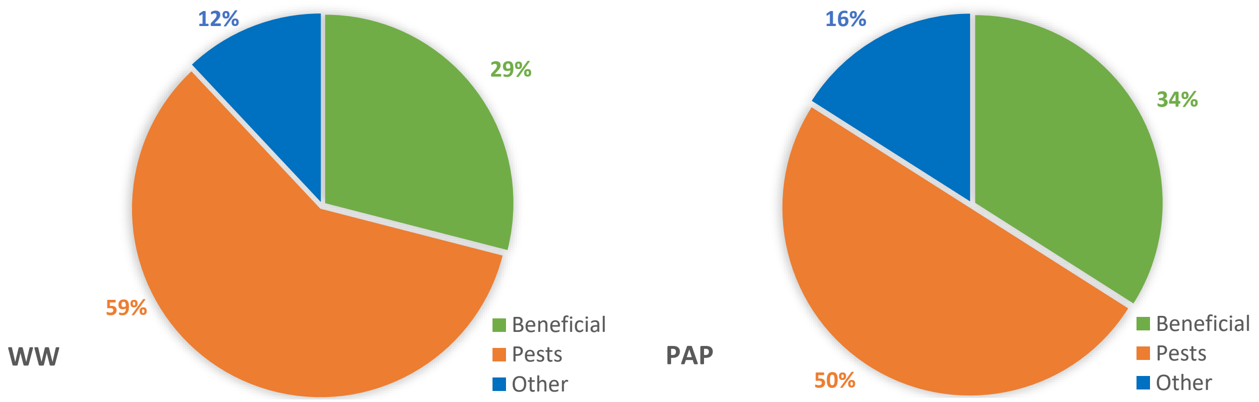
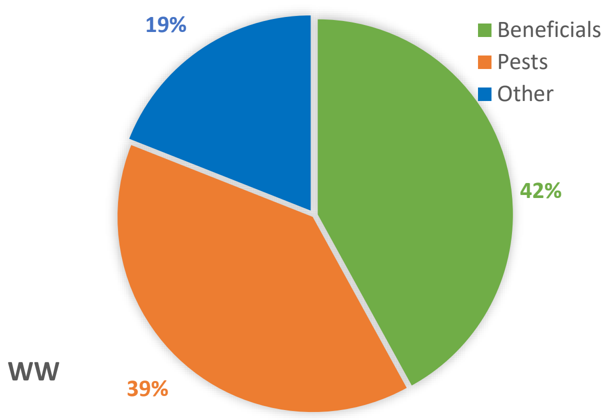


Figure 56. Percentage of pests and beneficial insects recorded at WW and PAP during sweep netting in 2022.



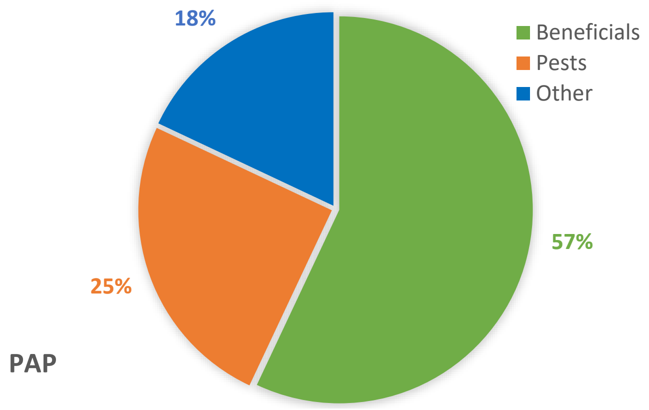


Figure 57. Percentage of pests and beneficial insects recorded at WW and PAP in pitfall traps in 2022.

There was a larger percentage of pests than beneficial insects captured in sweep net transects and pitfall traps at WW compared to PAP, despite the large population of aphids present at PAP in 2022. This is similar to results recorded in 2021. The site at PAP is a regenerative farm, and no insecticides are applied across the whole farm.

Conclusions

Bruchid beetle damage was more severe at WW compared to PAP in 2022, and pea and bean weevils and aphids were the dominant pest species at PAP (Table 5). Higher numbers of pest species were recorded in traps at WW, and very low numbers at PAP, except during March when high numbers of weevils were recorded at PAP (Figure 11). It is possible that weevils were attracted to the traps in March at PAP, before crop emergence, and attracted into the crop following emergence, leading to more damage at the second assessment.

There was an association between pea and bean weevil damage at the first assessment and yield at WW, and at the second assessment at PAP (Table 4). Yield was associated with bruchid damage at WW field 1 which contained the lure stations, and the control field at PAP (Table 4). Plant density and yield were strongly associated at WW and the trap crop field at PAP (Table 6). This was not the case in the control field at PAP as crop establishment was very poor.

Higher levels of pea and bean weevil damage and numbers of aphids per plant at PAP may have been due to the fact the crop developed very poorly and establishment was much lower at PAP than at WW in 2022, allowing pests to cause more damage per plant. Bruchid beetles may have been less attracted to the crop at PAP due to lower flowering density.

At WW, field 1 contained the trap crop with lures, fields 2 and 3 trap crops without lures and field 4 had not trap crop or lures. The level of damage caused by pea and bean weevil and bruchid beetle showed a similar effect in all fields with trap crops, indicating that the effect was a result of the presence of trap crops and not the lure stations. There was an effect of field edge on weevil damage in field 4, although levels of damage from bruchid beetle were slightly lower in the trap crop in field 4 compared to the other fields.

The highest level of aphid infestation was recorded in field 4 compared to the fields containing trap crops at WW. There is no clear reason for this. None of the fields was treated with an aphicide until after the aphid assessment.

At PAP bruchid beetles were recorded at low levels in the field and in the traps, and no difference was found between the trap crop field and the control field. Both weevil assessments indicated that there was a significant difference between the bean area adjacent to the trap crop and the control crop, the control area having the highest level of damage. Aphid damage was very high at PAP and although there was no significant difference between the area adjacent to the trap crop and the control area, there was a significant difference at distance 10 and 20 metres into the crop compared to 50 and 100 metres into the crop, indicating a strong field edge effect.

The highest incidence of weevil damage at WW was in the trap crop area of field 1, indicating that the pea and bean pheromone lures may have provided added attraction into the trap crop area. At WW for all fields, there was a reduction in bruchid damage as distance from the trap crop increased, including the field which did not contain a trap crop (field 4). No conclusions can be drawn from aphid data collected at WW in 2022.

The trap crop area in Field 3 at WW was treated with a pyrethroid insecticide for bruchid beetle control, although this appears from the data to have had no effect on bruchid damage levels in this area, which were not significantly different from the levels of damage recorded in the trap crops in the other fields (Table 5). It is likely that resistance to pyrethroids is present in some bruchid beetle populations, and this may be the reason for the ineffectiveness of insecticide applications here.

Other insects were recorded at all sites using sweep netting and pitfall traps, and a biodiversity index calculated using the Simpson Index. At WW the pitfall data was combined from all fields and indicated that insect diversity was higher closer to the edge of the field and declined at a distance of 100 metres from the edge (Figure 52). The same trend occurred at PAP, and the beetle bank had a similar insect diversity to the edge of the field, despite being 100 metres from the edge of the field.

The sweep netting provided a different trend. At WW, sweep netting provided no consistent differences between the trap crop and 100 metres from the trap crop or field edge in any of the fields (Figure 53). At PAP (Figure 55) the lowest diversity was found in the trap crop field and the highest at 100 metres from the trap crop, while in the control field the opposite was true. It is not possible to determine the reason for this, although the control field did not establish well.

Sweep netting data were categorised into beneficial insects, pests, and other insect species (those that did not fit into either category) (Figures 56 and 57). This allowed a comparison of the sites, PAP having a higher proportion of beneficial insects compared to WW. This may be associated with the different farming system at PAP, where a regenerative approach is taken, and no insecticides are used on the farm. At WW, insecticides are used within the arable rotation when necessary. A similar result was observed in 2021.

References

Bruce, T.J.A., Martin, J.L., Smart, L.E. and Pickett, J.A. (2011). Development of semiochemical attractants for monitoring bean seed beetle, *Bruchus rufimanus. Pest Management Science.* **67**: 1303–1308.

Cárcamo, H.A., Vankosky, M.A., Wijerathna, A., Olfert, O.O., Meers, S.B. and Evenden, M.L. (2018) Progress Toward Integrated Pest Management of Pea Leaf Weevil: A Review. *Annals of the Entomological Society of America* **111(4)**, 144–153 doi: 10.1093/aesa/say007 Review.

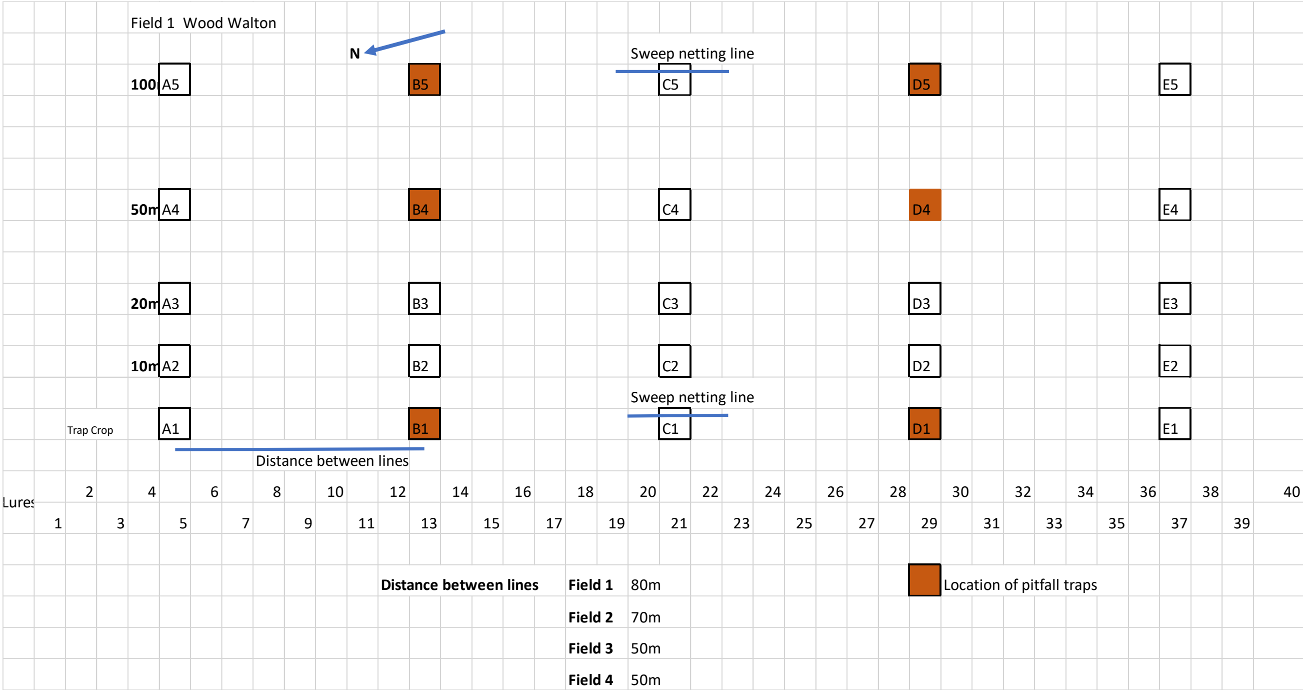
Delobel, B. and Delobel, A. (2006). Dietary specialisation in European species groups of seed beetles (Coleoptera: Bruchidae: Bruchinae). *Oecologia* **149**, 428-443.

Shelton, A.M. and Badenes-Perez, F.R. (2006). Concepts and applications of trap cropping in pest management. *Annual Review of Entomology* **51**, 285-308.

Smart, L.E., Blight, M.M., Pickett, J.A. and Pye, B.J. (1994). Development of field strategies incorporating semiochemicals for the control of the pea and bean weevil, *Sitona lineatus* L. *Crop Protection* **13.**

Ward, R., (2018). The biology and ecology of *Bruchus rufimanus* – PhD thesis. https://theses.ncl.ac.uk/jspui/bitstream/10443/4358/1/Ward%20%20R%20L%202018.pdf

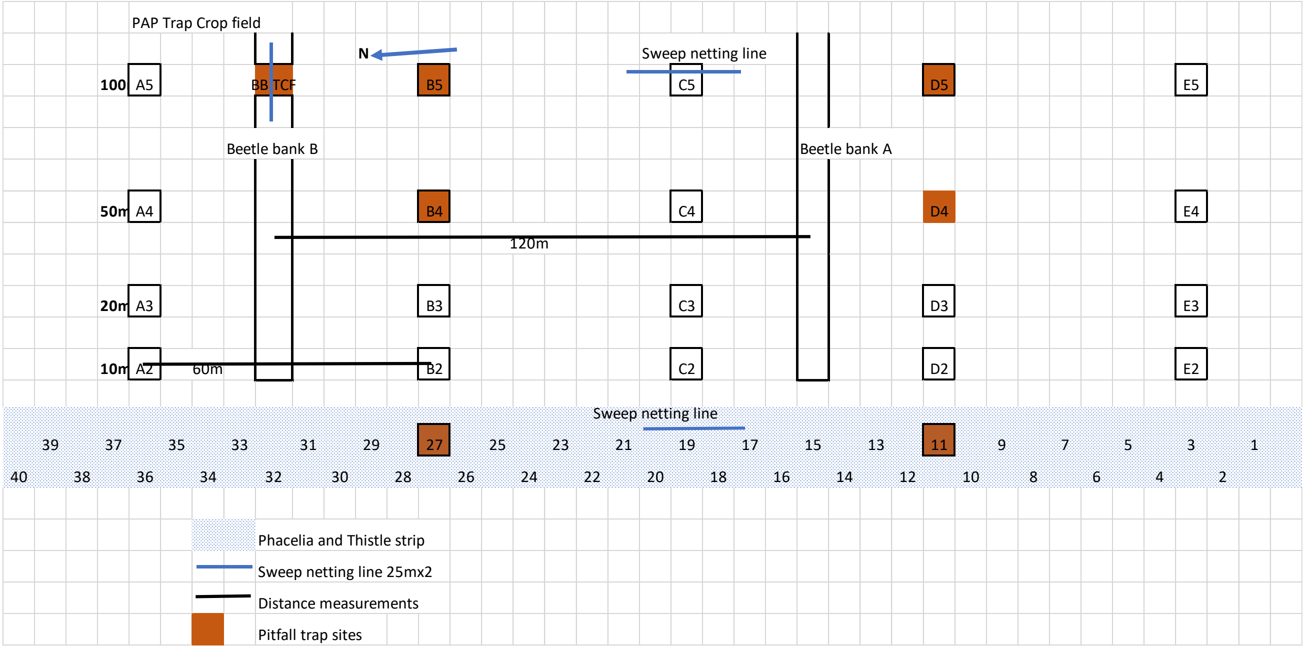
Appendix A.



Location of sample points, traps and sweep net transects at in WW 2022 in field 1. Weevil and bruchid traps were located 10 metres apart in the trap crop. Sweep netting was carried out along parallel lines of 25m length. All the fields at WW were set up identically except for the distance between the vertical rows, which are detailed above. As mentioned previously field 4 differed in that it did not have a trap crop, but the sample points were in the same position.

Location of traps and sweep net transects at all fields in WW in 2022.

Pitfall Traps		**Sweep netting**		
Trap crop	B1	Trap crop	C1	
	D1	Spring bean main crop	C5	
Spring bean main crop	B5			
	D5			



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.

Location of traps and sweep net transects at PAP in 2022.

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