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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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Dr Becky Howard
Mrs Shona Duffy
Mr Nicolo Vela

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. Three farm sites were studied in 2021, two of the sites having trap crops containing lucerne or vetch, and one site with an early sown spring faba bean trap crop. Effects of trap crops on pest levels were observed in 2021, and the early sown spring faba bean trap crop appeared to have the clearest effect on pest levels in the main crop. Trap crops containing lucerne may have influenced the level of pea and bean weevil damage in winter sown beans at one of the sites.

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

Three sites with different farming regimes and approaches to insect pest management were established in late 2020. Figure 1 shows farm locations and table 1 summarises the type of farming system at each site. No insecticides were applied to any of the field bean sites in 2021. At each location 40 pheromone and 40 plant volatile bait stations were located within the trap crop. Figures 2 to 4 show the location of the trap crop within the crop at each site. Figures I-IV and Tables I to V, Appendix A, show the layout of additional sampling points at all sites, type of trap and method of sampling used. At site MID, lucerne was established in the trap crops A and B in July 2020 and trap crop C was a grass and flower mixture. Winter beans were sown in October 2020 as the main crop and there was no control area for comparison (Figure 2). At site PAP, spring field beans were sown in April 2021 as the main crop and there was an area used as a control area that did not contain a trap crop area (Figure 3). The trap crop was a long-term legume-rich margin that included vetch. At site HH there were two fields containing trap crops, one was used without additional pheromone and plant volatile insect lures, and one with (Figure 4). The trap crop in both fields was spring field beans sown in early January, and the main crop was spring field beans sown in April 2021.

Figure 1: *Map of the location of trap crop farm sites in 2020-2021*

Table 1: *Farm details for the trap cropping sites in 2020-2021*

Site reference	Location (OS grid reference)	Cultivation System	Whole farm spray regime	Crop	Trap crop details	Crop sown
PAP	TL27696192	Crops drilled directly into stubble	No insecticides	Spring Beans	Long term legume rich field margin	10th April 2021
MID	TL16006430	Plough-based	Insecticides only if required	Winter Beans	Mixture of lucerne and wild bird mixture (Figure IV, Appendix B)	14th October 2020
HH	TL28477640 TL27827584	Plough-based	Standard insecticide programme	Spring Beans	Spring beans sown in January	5th April 2021

Figure 2: *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.*

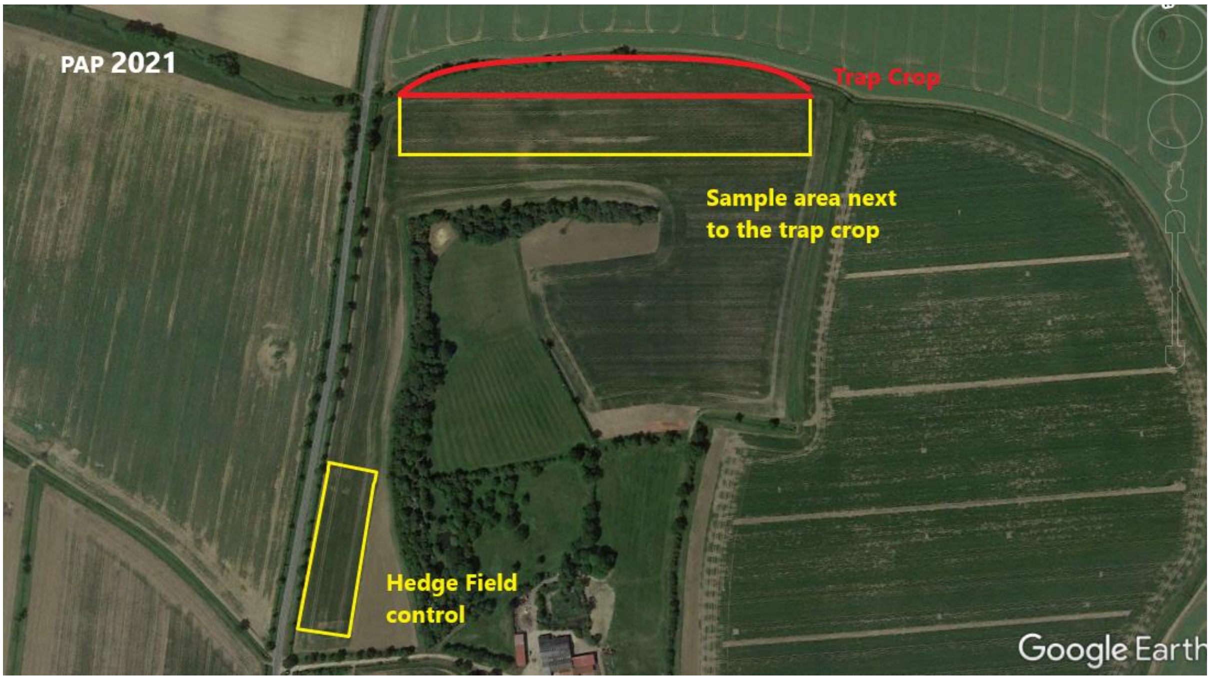

Figure 3: *Layout of sampling site at PAP in 2021*.

Figure 4: *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.*

Tables 2, 3 and 4 show the timing of assessment or collection for all monitoring activities for the duration of the season at each site.

Table 2: *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.

Table 3: *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 4: *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 Main crop 74	Bruchid station; sweep net transects; emergence traps checked.
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

Plant density

Plant density was calculated by counting 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 5). 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. Specific details of location of traps at each site can be found in Figures I, II and IV in Appendix A.

Figure 5: *Pea and bean weevil pheromone baited station in situ and 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 6). 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 Figures I, II and IV in Appendix A.

Figure 6: *Bruchid beetle plant volatile baited station in situ and adult bruchid beetle in field bean crop.*

The pea and bean weevil and bruchid beetle bait stations were emptied at two-week intervals, all insects collected and returned to the laboratory where they were frozen for a short period. The number of each species was recorded after examination under a low powered microscope.

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 7).

Figure 7: *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 HH five additional samples were taken from each of the trap crops, corresponding with lines A to E (Figure IV, 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 PP1/175 (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 8).

Figure 8: *Exit holes caused as adult bruchid beetles emerge from seeds at maturity, brown marks caused by larvae under the seed coat, and circular 'window' on the seed surface.*

Emergence traps

Emergence traps were assembled in the field to monitor weevil emergence from soil following pupation and completion of their life cycle. Figures I to IV and Tables I to V in Appendix A show the locations of the traps within each field. Emergence traps consisted of net covers placed over a flexible frame to form a small 'tent' (Figure 9). At the apex of each emergence trap there was a bulb in which insects were collected. Weevils were collected on two or three occasions at each site and returned to the lab where they were frozen for a short period. Captured pea and bean weevils were recorded on each occasion and dates of collection are shown in Tables 2 to 4.

Figure 9: *Pea and bean weevil emergence trap in situ.*

Biodiversity monitoring

Sweep netting

Figures I to IV and Tables I, II, II and V (Appendix A) give details of the location of the sweep net transects, and Tables 2 to 4 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 10). 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 10: *Sweep netting at MID in 2021.*

<u>Pitfall Traps</u>

Pitfall traps with 250 ml capacity were placed at regular locations at each site in both the main crop and the trap crop at the end of March (winter bean MID) or mid-April (PAP and HH) (Figure I, II and IV and Tables I, II, IV and V, 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 11 and 12). These were emptied every two weeks into a resealable labelled bottle, returned to the laboratory, and refrigerated for a period until identification and recording of insects took place.

Figure 11: *Pitfall trap in situ 2021.*

Figure 12: *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 HH five additional samples were taken from each of the trap crops, corresponding with lines A to E (Figure IV, 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 expressed as mean percentage seed damage at each sampling point by number of seeds. Pea and bean weevil damage was expressed as mean damage per plant (number of notches) at each sampling point. 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.

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 (if present) at each site, and if the presence of the trap crop influenced these factors. The analysis was carried out using Microsoft Excel.

Results

Pest damage and yield at all sites 2021

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 some significant associations between yield and the mean number of weevil notches per plant at sites HH and MID (Table 5). Table 5 shows a significant association between mean percentage bruchid damage and yield at MID, 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 pest damage and yield at PAP. Overall pest damage was lower at PAP than at MID or HH (Table 6)

Table 5: *Regression analysis statistics for all sites, comparing pest damage from pea and bean weevils and bruchid beetles against yield at each sampling point in 2021. Figures highlighted in bold are statistically significant.*

		Pea and bean weevil damage vs yield		Bruchid damage vs yield	
		R-Squared	p-value	R-squared	p-value
HH	Field 9 (no lures)	0.273350	**0.018017**	0.192698	0.052824
	Field 10 (lures)	0.129456	0.119189	0.169131	0.071631
PAP	Trap Crop Field	0.154268	0.086704	0.019002	0.562216
	Hedge Field	0.016889	0.687274	0.036755	0.550568
MID	MID	0.268973	**0.022901**	**0.47457**	**0.001151**

Table 6: *Mean percent damage to seed caused by bruchid beetles (by number of seeds) and mean number of pea and bean weevil notches per plant recorded at each site in 2021.*

Site	Mean % bruchid damage	Mean number of pea and bean weevil notches per plant
PAP	11.72	6.23
MID	13.47	20.47
HH9 (no lures)	21.66	8.94
HH10 (lures)	23.29	23.03

Site MID

Pest damage	0-10	10.01-20	20.01-30	30.01-40	40.01-50
Plant density winter beans (MID)	0-10	10.01-20	20.01-30	30.01-40	40.01-50

Figure 13: *Key for pest damage and plant density heat maps in Figures 14 to 16.*

		A	B	C	D	E	
4	Trap crop A	11.03	21.75	25.68	22.64	45.05	Trap crop C
3		8.46	21.73	10.73	25.82	40.41	
2		10.61	17.52	15.2	20.74	32.74	
1		11.54	12.23	13.29	16.24	26.08	
				Trap crop B			

Figure 14: *Mean pea and bean weevil damage as notches per plant at each sampling point at MID in 2021.*

		A	B	C	D	E	
4	Trap crop A	17.43	6.48	6.34	9.29	28.4	Trap crop C
3		12.69	5.4	12.91	8.71	27.73	
2		8.64	12.56	9.45	7.86	19.67	
1		8.59	19.12	13.08	10.68	24.2	
				Trap crop B			

Figure 15: *Mean bruchid beetle damage to seed as percentage number of seeds at each sampling point at MID in 2021.*

		A	B	C	D	E	
4	Trap crop A	35	33	25	36	15	Trap crop C
3		35	35	32	23	24	
2		35	37	43	32	29	
1		37	40	40	35	16	
				Trap crop B			

Figure 16: *Mean plants per square metre at each sampling point at MID in 2021 (target plant density for winter beans is 20 to 30 plants per square metre)*

Pest damage in line E at MID was present at higher levels for both pea and bean weevil and bruchid beetle compared to other lines (Figures 14 and 15). It is possible that this was related to the lower plant density recorded in line E (Figure 16), where lower plant frequency per square metre may have led to higher pest density per plant, resulting in greater damage to foliage from pea and bean weevil adults, and greater damage to seed caused by bruchid beetle larvae. Plant density in line E may have been affected by flooding during the winter of 2020-2021.

There appeared to be less damage from pea and bean weevil adults to foliage closer to trap crops A and B.

Table 7: *Number of adult weevils recorded in emergence traps at MID in 2021, with totals for each row and column as laid out in Figure I, Appendix A.*

	09/07/2021	23/07/2021	04/08/2021
B1	0	9	62
B2	0	3	194
B3	0	5	108
B4	0	12	133
D1	0	2	97
D2	0	15	115
D3	0	1	123
D4	0	6	9
Total column B			526
Total column D			368
Total row 1			170
Total row 2			327
Total row 3			237
Total row 4			160
Mean per emergence trap			111.75

There were no clear distribution patterns of adult pea and bean weevil emergence following pupation during July and August 2021 at MID (Table 7). Higher numbers of adults were recorded in column B and row 2, as laid out in the plan in Figure I, Appendix A. Column B was closer to the lucerne strip in trap crop A.

Site PAP

Pest damage	0-10	10.01-20	20.01-30	30.01-40	40.01-50	50.01-60	60.01-70
Plant density spring beans (PAP and HH)	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		

Figure 17: *Key for pest damage heat maps in Figures 18 to 29.*

	A	B	C	D	E
4	5.58	6.42	5.08	7.62	5.86
3	5.22	5.36	4.52	5.72	8.42
2	5.68	7.24	5.4	5.46	8.8
1	3.8	6.26	6.88	6.28	9.08

Trap crop

Figure 18: *Mean pea and bean weevil damage as notches per plant at each sampling point at PAP in 2021.*

	A	B	C	D
3	3.84	4.34	3.34	5.48
2	6	7.22	5.18	8.44
1	10.28	10.32	10.86	8.4

Figure 19: *Mean pea and bean weevil damage to seed as percentage number of seeds at each sampling point in the control area at PAP in 2021.*

	A	B	C	D	E
4	5.96	6.62	26.44	10.64	19.35
3	15.57	8.68	15.82	8.8	17.95
2	8.64	11.73	13.95	12.79	14.52
1	2.1	9.66	8.27	10.03	6.8

Trap crop area

Figure 20: *Mean bruchid beetle damage to seed as percentage number of seeds at each sampling point at PAP in 2021.*

	A	B	C	D
3	8.4	11.62	14.8	9.48
2	8.66	12.74	11.65	17.29
1	1.88	7.05	14.2	10.12

Figure 21: *Mean bruchid beetle damage to seed as percentage number of seeds at each sampling point in the control area at PAP in 2021.*

	A	B	C	D	E
4	36	22	25	32	30
3	22	34	33	33	25
2	21	21	35	24	14
1	31	38	31	22	31

Trap crop area

Figure 22: *Mean plants per square metre at each sampling point at PAP in 2021 (target plant density for spring beans is 45 to 55 plants per square metre).*

	A	B	C	D
3	39	46	40	31
2	28	37	43	37
1	35	31	31	38

Figure 23: *Mean plants per square metre at each sampling point in the control area at PAP in 2021 (target plant density for spring beans is 45 to 55 plants per square metre).*

There were no significant associations between pest damage from either pea and bean weevil or bruchid beetle damage and yield at PAP (Table 5). There was no observed impact of the trap crop on pest pressure at PAP (Figures 18 to 21). Pest pressure at PAP was lower overall than at either MID or HH (Table 6).

One-tail t-test analysis was carried out using Microsoft Excel to determine whether there was a significant difference in yield or pest damage between the field containing the trap crop and the control area (Hedge field) and if the presence of the trap crop influenced these factors. There were no significant differences in pest damage between the two areas (Tables 9 and 10), although yield of the control area was significantly higher than that in the area containing the trap crop (Table 8).

Table 8: *Results of t-test (two-sample) to determine whether there was a significant difference in yield between the field containing the trap crop and the control area (Hedge Field) at PAP in 2021.*

Variable: Yield	Trap Crop Field	Control area (Hedge Field)
Mean	5.04978	6.332525
Variance	2.631847	4.3952522
Observations	20	12
P(T<=t) one-tail	**0.042436**	

Table 9: *Results of t-test (two-sample) to determine whether there was a significant difference in bruchid beetle damage between the field containing the trap crop and the control area (Hedge Field) at PAP in 2021.*

Variable: Bruchid beetle damage	Trap crop field	Control area (Hedge field)
Mean	11.71592003	10.65650491
Variance	30.6707715	16.43137313
Observations	20	12
P(T<=t) one-tail	**0.284750583**	

Table 10: *Results of t-test (two-sample) to determine whether there was a significant difference in pea and bean weevil damage between the field containing the trap crop and the control area (Hedge Field) at PAP in 2021.*

Variable: Pea and bean weevil damage	Trap crop Field	Control area (Hedge Field)
Mean	6.234	6.975
Variance	1.961562	7.075864
Observations	20	12
P(T<=t) one-tail	**0.154238**	

Table 11: *Number of adult weevils recorded in emergence traps in the trap crop field at PAP in 2021, with totals for each row and column as laid out in Figure II, Appendix A and mean number of adults per emergence trap.*

Date	05/07/2021	20/07/2021	02/08/2021	24/08/2021
B1	0	0	0	3
B2	0	0	2	18
B3	0	0	1	22
D1	0	0	1	26
D2	0	0	0	4
D3	0	0	1	0
Total column B				46
Total column D				32
Total row 1				30
Total row 2				24
Total row 3				24
Mean per emergence trap				13

There were no clear distribution patterns of adult pea and bean weevil emergence following pupation during July and August 2021 in the trap crop field at PAP (Table 11).

Table 12: *Number of adult weevils recorded in emergence traps in the control field (Hedge field) at PAP in 2021, with totals for each row and column as laid out in Figure III, Appendix A and mean number of adults per emergence trap.*

Date	05/07/2021	20/07/2021	02/08/2021	24/08/2021
B1	0	0	3	1
B2	0	2	8	32
B3	0	1	2	19
Total column B				68
Total row 1				4
Total row 2				42
Total row 3				22
Mean per emergence trap				22.67

There was a higher number of emerging adults following pupation in the control field compared to the field containing a trap crop (Tables 11 and 12).

Site HH

In fields 9 and 10 at HH the level of damage from pea and bean weevil was higher in the early-sown spring bean trap crop area compared to the main crop area (Figures 24 and 25). Pea and bean weevil foliar damage was lower in the samples that were further away from the trap crop area, regardless of whether lures were present in the trap crop.

	A	B	C	D	E
4	1.53	1.07	1.47	1.36	1.44
3	2.65	1.69	3.41	3.77	1.53
2	6.17	4.07	7.56	5.59	1.77
1	7.91	7.36	10.19	8	5.31
Trap crop →	31.76	24.87	28.6	29.68	24.63

Figure 24: *Mean pea and bean weevil damage as notches per plant at each sampling point at HH field 9 (trap crop area containing no pheromone or plant volatile lures) in 2021.*

	A	B	C	D	E
4	1.73	1.77	2.76	4.44	2.36
3	8.67	6.91	10.23	8.88	10.72
2	17.67	16.04	18.51	20.73	22.95
1	22.79	26.76	27.84	26.92	28.63
Trap crop →	52.23	56.13	56.6	60.12	63.4

Figure 25: *Mean pea and bean weevil damage as notches per plant at each sampling point at HH field 10 (trap crop area containing pheromone and plant volatile lures) in 2021.*

In fields 9 and 10 at HH bruchid beetle damage was higher in the trap crop area than the main crop area (Figures 26 and 27).

	A	B	C	D	E
4	10.87	20.23	21.61	17.73	21.27
3	3.72	9.19	15.42	23.08	19.48
2	21.83	6.29	14.59	15.02	15.56
1	19.9	9.96	11.84	19.51	24.11
Trap crop →	55.98	37.11	32.53	50	44.59

Figure 26: *Mean bruchid beetle damage to seed as percentage number of seeds at each sampling point at HH field 9 (trap crop area containing no pheromone or plant volatile lures) in 2021.*

	A	B	C	D	E
4	7	21.46	9.73	15.19	13.58
3	12.08	15.14	12.81	17.13	22.5
2	27.35	25.63	17.69	9.82	30.56
1	14.98	17.24	19.75	27.23	30.99
Trap crop →	44.6	38.36	35.13	45.07	51.27

Figure 27: *Mean bruchid beetle damage to seed as percentage number of seeds at each sampling point at HH field 10 (trap crop area containing pheromone and plant volatile lures) in 2021.*

Plant density in fields 9 and 10 at HH was slightly higher than would normally be expected for spring beans, as target plant density for spring-sown beans is 45-55 plants per square metre (Figures 28 and 29). Plant density in field 9 was higher than in field 10.

	A	B	C	D	E
4	52	54	58	58	75
3	55	91	63	68	88
2	64	66	68	67	61
1	59	49	42	58	60
Trap crop →	43	57	56	49	52

Figure 28: *Mean plants per square metre at each sampling point at HH field 9 (trap crop area containing no pheromone or plant volatile lures) in 2021 (target plant density for spring beans is 45 to 55 plants per square metre).*

	A	B	C	D	E
4	64	58	55	37	54
3	46	60	44	49	54
2	56	56	73	53	51
1	51	60	51	44	33
Trap crop →	38	45	40	41	42

Figure 29: *Mean plants per square metre at each sampling point at HH field 10 (trap crop area containing pheromone and plant volatile lures) in 2021 (target plant density for spring beans is 45 to 55 plants per square metre).*

Yield was higher in the early-sown spring bean trap crop area in both fields 9 and 10 at HH in 2021. Mean yield in the trap crop area in field 9 was 10.37 t/ha compared to 6.80 t/ha in the main crop. Mean yield in the trap crop area in field 10 was 11.77 t/ha compared to 6.76 t/ha in the main crop. This reflects the earlier sowing timing of the beans.

Regression analysis of mean percentage damage against yield from samples taken from the main crop in field 9 at HH showed that significantly higher levels of pea and bean weevil damage led to lower yield. In field 10 there was no significant association between weevil damage to foliage and yield (Table 5). There were no significant associations between mean bruchid beetle damage to seed and yield for either field at HH in 2021.

T- test analysis was carried out for fields 9 and 10 at HH to determine whether the presence of lures in the trap crop affected yield, weevil damage or bruchid damage in the whole crop including the trap crop area. There was no significant difference in yield between the two fields (Table 13).

Table 13: *Results of t-test (two-sample) to determine whether there was a significant difference in yield between fields 9 and 10 at HH in 2021.*

Variable: yield	Field 9 (no lures)	Field 10 (lures)
Mean	7.511772	7.762692
Variance	4.127612	8.290867
Observations	25	25
t Stat	-0.35602	
P(T<=t) one-tail	**0.361694**	

There was no significant difference in percentage bruchid beetle damage between fields 9 and 10 at HH in 2021 (Table 14).

Table 14: *Results of t-test (two-sample) to determine whether there was a significant difference in percentage bruchid beetle damage between fields 9 and 10 at HH in 2021.*

Variable: bruchid beetle seed damage	Field 9 (no lures)	Field 10 (lures)
Mean	21.65718	23.29094
Variance	172.2861	146.3375
Observations	25	25
P(T<=t) one-tail	**0.32464**	

There was a significant difference in the level of pea and bean weevil damage between fields 9 and 10 at HH in 2021 (Table 15), indicating the possibility that the pea and bean weevil pheromone attracted weevils into the crop at greater levels in field 10. The results in Table 15 also include damage to the trap crop area. When the trap crop data were removed, the average weevil damage to field 9 was 4.19% compared to 14.36% in field 10.

Table 15: *Results of t-test (two-sample) to determine whether there was a significant difference in pea and bean weevil damage between fields 9 and 10 at HH in 2021.*

Variable: pea and bean weevil damage	Field 9 (no lures)	Field 10 (lures)
Mean	8.935467	23.03093
Variance	101.7834	389.1088
Observations	25	25
Pooled Variance	245.4461	
P(T<=t) one-tail	**0.001287**	

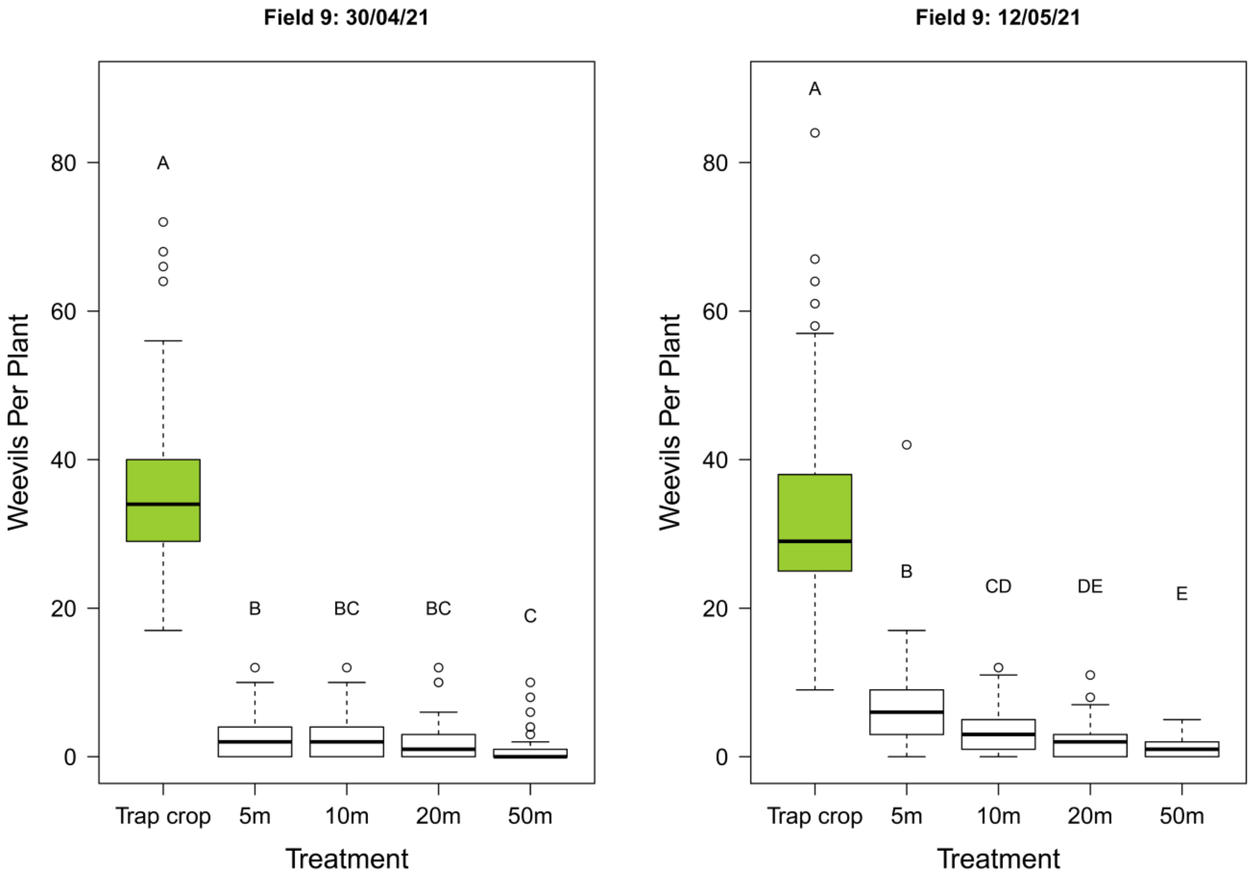

Figure 30: *Mean number of weevil notches per plant at sampling points within the trap crop and at 5, 10, 20 and 50 metres distance from the trap crop in field 9 (without lures) at HH on 30th April and 12th May 2021. Means with the same letter are not significantly different.*

The mean number of pea and bean weevil notches per plant was higher in the trap crop compared to the main crop at two assessments carried out on 30th April and 12th May 2021 in field 9 at HH in 2021. There was a significant decline in the level of pea and bean weevil damage as distance from the trap crop area increased (Figure 30).

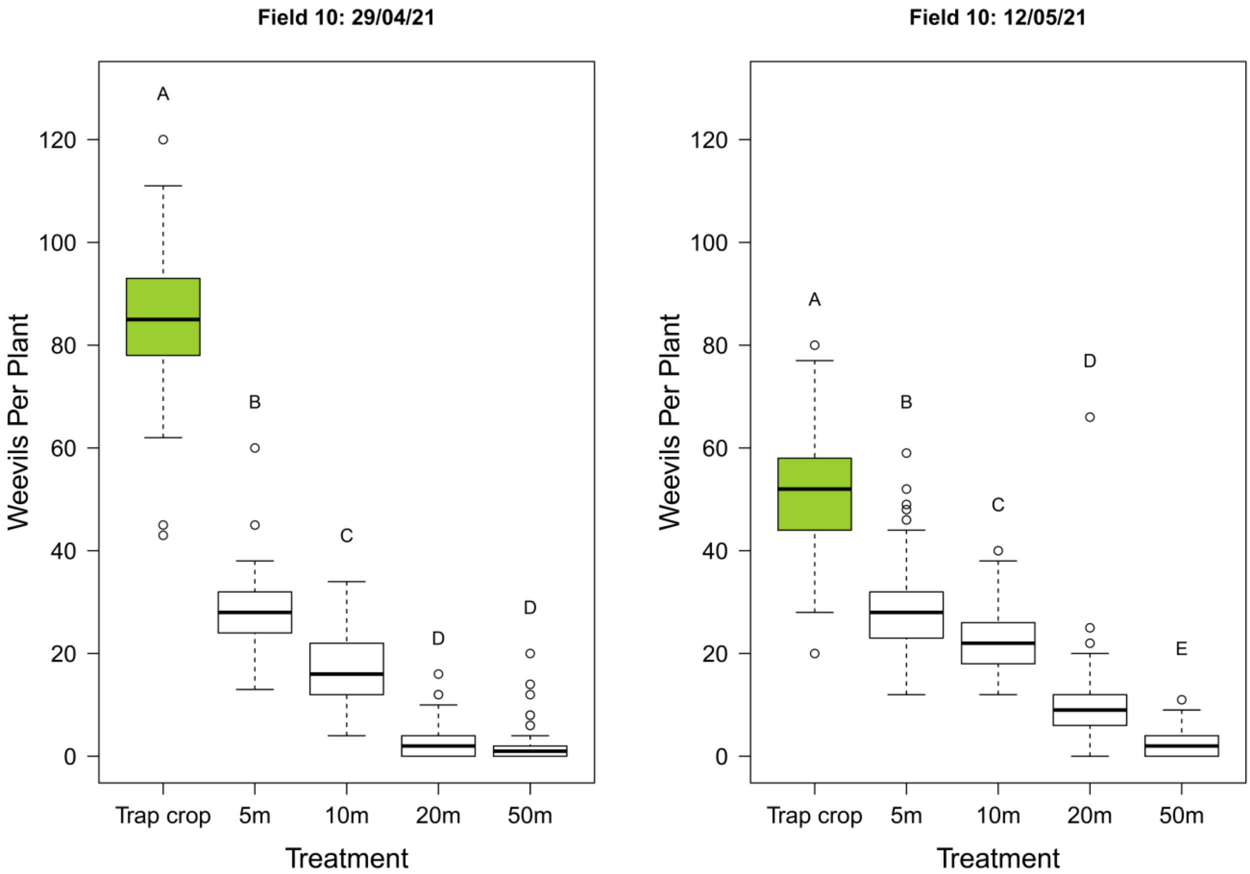

Figure 31: *Mean number of weevil notches per plant at sampling points within the trap crop and at 5, 10, 20 and 50 metres distance from the trap crop in field 10 (with lures) at HH on 29th April and 12th May 2021. Means with the same letter are not significantly different.*

The mean number of pea and bean weevil notches per plant was higher in the trap crop compared to the main crop at two assessments carried out on 29th April and 12th May 2021 in field 10 at HH in 2021. There was a significant decline in the level of pea and bean weevil damage as distance from the trap crop area increased (Figure 31). At the second assessment on 12th May the level of pea and bean weevil damage on new growth had declined but there were significantly different levels of damage between the sampling points as distance from the trap crop increased. Overall levels of pea and bean weevil damage were higher in field 10 in which pheromone lures were placed in the trap crop, compared to field 9 in which there were no lures placed into the trap crop area. In both fields there was a strong effect of the trap crop in reducing the level of damage in the main crop, and this effect continued as distance from the trap crop increased.

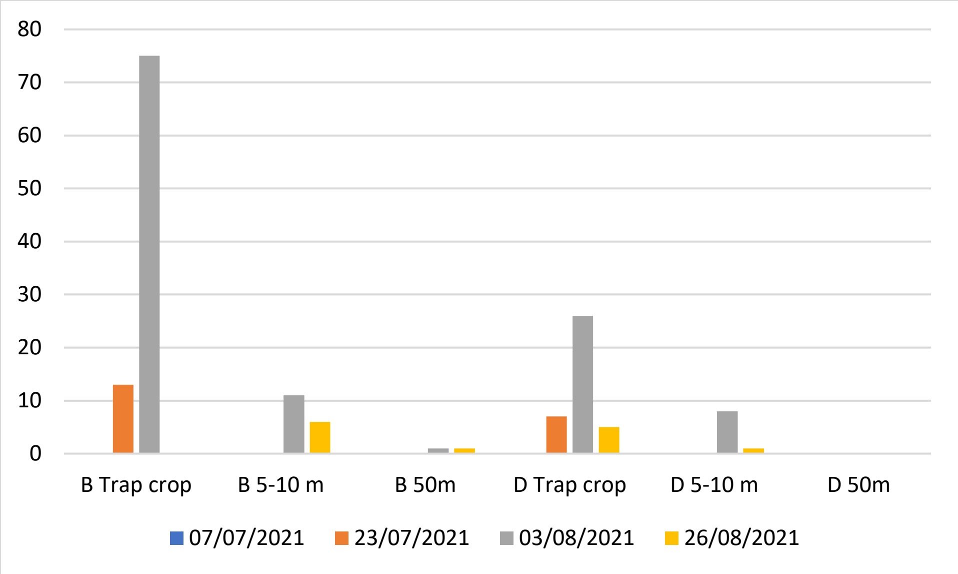

Figure 32: *Total number of adult pea and bean weevils recorded in emergence traps placed within the trap crop and at different distances from the trap crop at field 9 (without lures) at HH in 2021.*

Table 16: *Number of adult weevils recorded in emergence traps in field 9 (without lures) at HH in 2021, with totals for each row and column as laid out in Figure IV, Appendix A and mean number of adults per emergence trap in both the trap crop and the main crop.*

Date	07/07/2021	23/07/2021	03/08/2021	26/08/2021
Trap crop (column B)	0	13	75	0
B2/ B3	0	0	11	6
B4	0	0	1	1
Trap crop (column D)	0	7	26	5
D2/ D3	0	0	8	1
D4	0	0	0	0
Total trap crop				126
Total main crop				28
Total column B (main crop)				19
Total column D (main crop)				9
Total row 2/3 (main crop)				26
Total row 4 (main crop)				2
Mean per emergence trap (trap crop)				63
Mean per emergence trap (main crop)				7

Higher numbers of adult pea and bean weevils were recorded in emergence traps in the trap crop at HH compared to the main crop in field 9 (Table 16). The number of emerging adults declined further away from the trap crop (Figure 32).

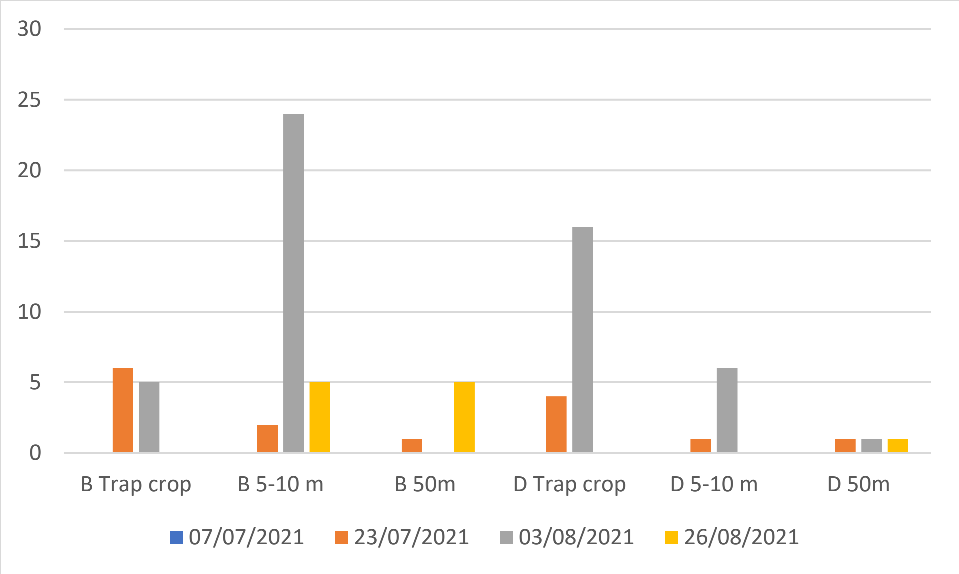

Figure 33: *Total number of adult pea and bean weevils recorded in emergence traps placed within the trap crop and at different distances from the trap crop at field 10 (with lures) at HH in 2021.*

Table 17: *Number of adult weevils recorded in emergence traps in field 10 (with lures) at HH in 2021, with totals for each row and column as laid out in Figure IV, Appendix A and mean number of adults per emergence trap in both the trap crop and the main crop.*

	07/07/2021	23/07/2021	03/08/2021	26/08/2021
Trap crop (column B)	0	6	5	0
B2/ B3	0	2	24	5
B4	0	1	0	5
Trap crop (column D)	0	4	16	0
D2/ D3	0	1	6	0
D4	0	1	1	1
Total trap crop				31
Total main crop				47
Total column B (main crop)				37
Total column D (main crop)				10
Total row 2/3 (main crop)				38
Total row 4 (main crop)				9
Mean per emergence trap (trap crop)				15.5
Mean per emergence trap (main crop)				11.75

Slightly higher numbers of adult pea and bean weevils were recorded in emergence traps in the trap crop at HH compared to the main crop in field 10 (Table 17). The number of emerging adults declined further away from the trap crop (Figure 33) although results were less clear than those recorded in field 9 (Figure 32).

Biodiversity monitoring

Site MID

Table 18: *Total number of insects recorded in all pitfall traps during April, May and June 2021 at MID. Where identification to species was not possible, insects were identified to order, family or genus.*

Scientific name	15/04/2021	26/04/2021	10/05/2021	27/05/2021	10/06/2021
Araneae spp.	59	52	123	123	81
Opiliones spp.	0	0	0	0	1
Deroceras reticulatum	8	3	9	9	0
Diptera Spp.	0	1	24	24	6
Carabidae spp. (other)	9	4	29	23	6328
Amara spp.	13	133	116	116	0
Diplopoda spp.	14	1	3	3	0
Coccinellidae spp.	1	2	0	0	0
Bombus spp.	7	2	0	0	0
Colembola spp.	1	4	0	0	0
Palomena spp.	1	0	0	0	0
Armadillidium vulgare	0	0	0	0	11
Forficula auricularia	2	0	0	0	0
Sitona lineatus	4	27	92	92	0
Lepidoptera spp. (caterpillars)	0	0	2	2	0
Formicidae spp.	0	0	3	3	0
Apocrita spp. (parasitic wasps)	0	0	3	0	0
Helicidae spp.	0	0	1	1	0
Meligethes aeneus	0	1	0	0	0
Ceutorhynchus quadridens	0	0	1	1	0
Oulema melanopa	0	0	3	3	0

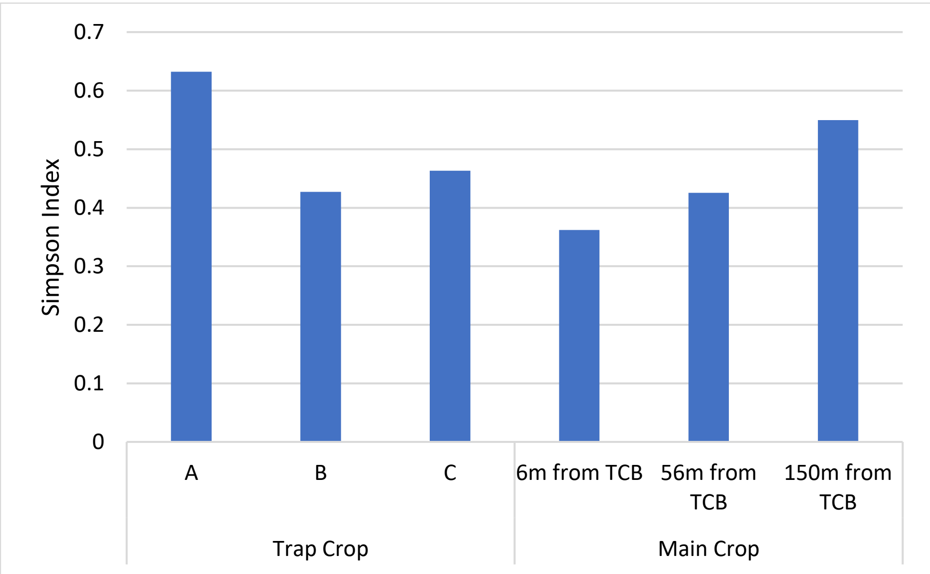

Figure 34: *Simpson Index calculated from all pitfall trap records at MID for each trap crop area and at 6, 56 and 150 metres from trap crop B in 2021. TCB = trap crop B.*

Higher diversity of insects was recorded in trap crop A at MID using the pitfall traps, and further away from trap crop B (Figure 34).

Table 19: *Total number of insects recorded in all sweep net samples during June and July 2021 at MID. Where identification to species was not possible, insects were identified to order, family or genus.*

Scientific name	10/06/2021	09/07/2021
Sitona lineatus	27	5
Bruchus rufimanus	3	4
Ceutorhynchus quadridens	0	2
Meligethes aeneus	82	37
Acyrthosiphon pisum	45	138
Myzus persicae	0	13
Aphis fabae	0	80
Apocrita spp. (parasitic wasps)	135	20
Diptera spp.	20	144
Syrphidae spp.	0	7
Palomena spp.	1	8
Cicadellidae spp.	2	13
Tipula spp.	0	1
Coccinellidae spp.	1	0
Araneae spp.	2	3
Carabidae spp. (other)	4	0
Psylliodes chrysocephala	0	2

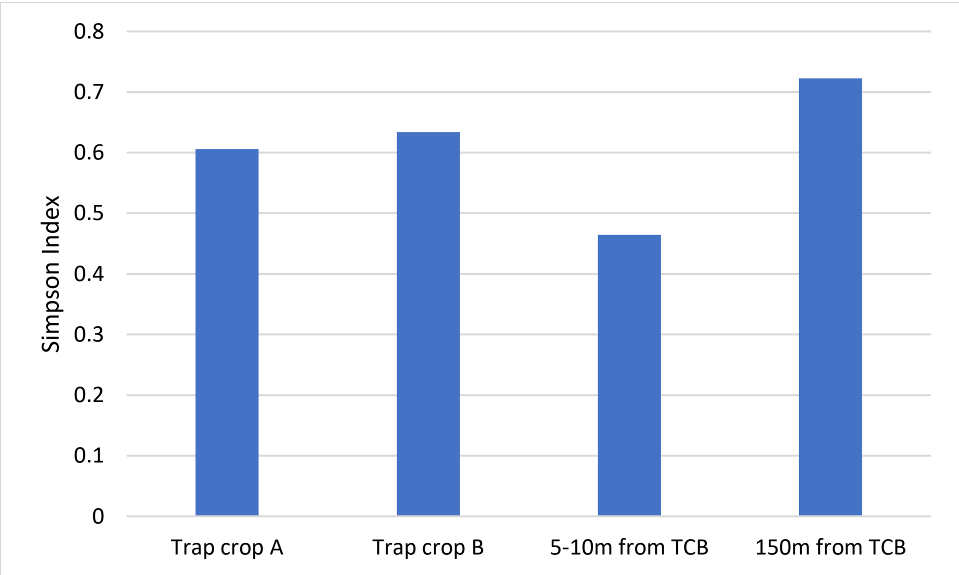

Figure 35: *Simpson Index calculated from all sweep netting records at MID for trap crops A and B and at 5-10 and 150 metres from trap crop B in 2021. TCB = trap crop B.*

The diversity of insects recorded in sweep nets was similar in trap crops A and B at MID and diversity increased with distance from trap crop B (Figure 35).

Site PAP

Table 20: *Total number of insects recorded in all pitfall traps during April, May and June 2021 in the trap crop field at PAP. Where identification to species was not possible, insects were identified to order, family or genus.*

	27/04/2021	11/05/2021	25/05/2021	07/06/2021
Araneae spp.	128	242	139	180
Opiliones spp.	0	3	10	12
Deroceras reticulatum	8	8	11	3
Diptera spp. (other)	2	4	8	69
Carabidae spp. (other)	5	32	143	1076
Amara spp.	6	2	2	17
Cassida vibex	6	6	5	3
Diplopoda spp.	8	9	1	17
Coccinellidae spp.	7	4	1	3
Colembola spp.	1	0	0	0
Armadillidium vulgare	0	2	5	0
Forficula auricularia	0	1	3	34
Sitona lineatus	12	32	9	2
Hypera positica	1	3	2	1
Lepidoptera spp. (caterpillars)	6	9	18	11
Formicidae spp.	0	0	58	12
Apocrita spp. (parasitic wasps)	0	16	48	2
Helicidae spp.	0	16	48	2

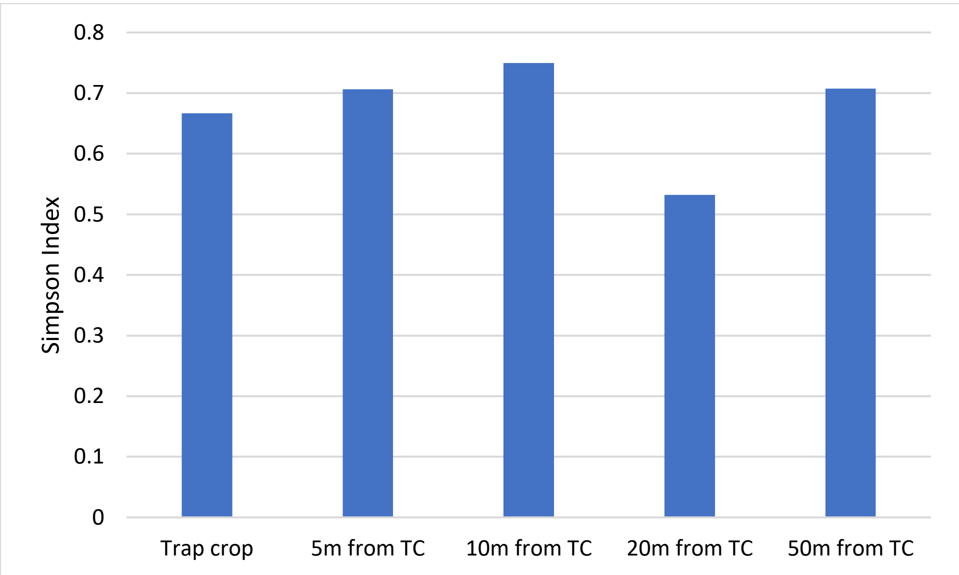

Figure 36: *Simpson Index calculated from all pitfall trap records at PAP for the trap crop area and at 5, 10, 20 and 50 metres from the trap crop in 2021. TC = trap crop.*

There were some differences in diversity of insects recorded in pitfall traps at PAP in 2021, and higher diversity was recorded 10 metres from the trap crop, although there were no clear patterns of distribution.

Table 21: *Total number of insects recorded in all sweep net samples during June, July and August 2021 in the trap crop field at PAP. Where identification to species was not possible, insects were identified to order, family or genus.*

	21/06/2021	05/07/2021	20/07/2021	02/08/2021
Sitona lineatus	16	9	4	159
Bruchus rufimanus	3	4	5	1
Hypera spp.	2	23	0	0
Ceutorhynchus quadridens	0	1	6	3
Hypera postica	0	0	2	0
Chrysopidae spp.	0	0	1	1
Meligethes aeneus	16	125	26	12
Acyrthosiphon pisum	16	20	15	2
Myzus persicae	0	7	0	0
Aphis fabae	0	1	0	1
Apocrita spp. (parasitic wasps)	0	15	0	0
Diptera spp.	136	33	187	114
Syrphidae spp.	0	0	11	18
Asilidae spp. (uncertain identification)	0	15	0	0
Palomena spp.	3	9	38	17
Cicadellidae spp.	1	2	38	5
Tipula spp.	9	1	0	0
Coccinellidae spp. (adult)	2	1	2	1
Coccinellidae spp. (larvae)	3	2	0	0
Araneae spp.	0	5	5	8
Opiliones spp.	0	0	5	6
Carabidae spp. (other)	1	0	2	1
Oedemera spp.	0	7	0	0
Zygoptera spp.	0	0	0	0
Lepidoptera spp. (caterpillar)	1	2	1	1
Gryllidae spp.	0	2	0	0
Armadillidium vulgare	1	2	1	3
Helicidae spp.	6	1	1	13
Forficula auricularia	0	1	0	3
Rhagonycha fulva	0	2	4	0
Lepidoptera spp.	0	1	0	0
Formicidae spp.	0	2	0	0

Table 22: *Total number of insects recorded in sweep net samples during June, July and August 2021 in the control field (Hedge field) at PAP. Where identification to species was not possible, insects were identified to order, family or genus.*

	21/06/2021	05/07/2021	20/07/2021	02/08/2021
Sitona lineatus	10	6	6	104
Bruchus rufimanus	0	2	2	1
Hypera spp.	0	0	1	0
Ceutorhynchus quadridens	0	0	1	0
Chrysopidae spp.	1	0	0	0
Meligethes aeneus	14	7	20	2
Acyrthosiphon pisum	2	5	11	8
Myzus persicae	0	0	0	1
Apocrita spp. (parasitic wasps)	0	7	0	0
Diptera spp.	98	42	104	86
Syrphidae spp.	0	3	2	6
Palomena spp.	0	0	4	4
Cicadellidae spp.	0	1	12	25
Tipula spp.	4	1	0	0
Coccinellidae spp. (adult)	2	0	2	0
Coccinellidae spp. (larvae)	4	6	0	0
Araneae spp.	0	0	6	1
Opiliones spp.	0	0	3	0
Oedemera spp.	0	0	2	0
Zygoptera spp.	2	0	0	0
Gryllidae spp.	1	0	0	0
Helicidae spp.	0	0	0	1
Rhagonycha fulva	0	0	2	0

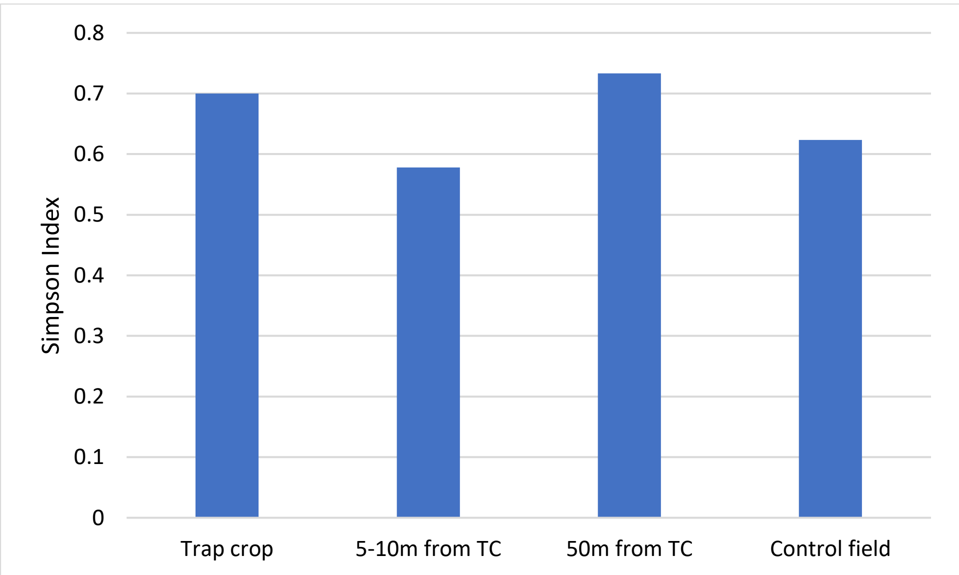

Figure 37: *Simpson Index calculated from all sweep netting records at PAP for the trap crop area, at 5-10 and 50 metres from the trap crop, and in the control field containing no trap crop in 2021. TC = trap crop.*

Diversity was greater in the trap crop and at 50 metres from the trap crop.

Site HH

Table 23: *Total number of insects recorded in all pitfall traps during April, May and June 2021 in field 10 (with lures) at HH. Where identification to species was not possible, insects were identified to order, family or genus.*

	29/04/2021	12/05/2021	26/05/2021	12/06/2021
Araneae spp.	12	15	42	16
Opiliones spp.	0	0	1	0
Deroceras reticulatum	0	1	0	1
Diptera spp.	28	27	115	80
Carabidae spp. (other)	2	6	0	2380
Amara spp.	17	28	131	0
Diplopoda spp.	0	1	0	0
Bombus spp.	0	1	0	0
Armadillidium vulgare	0	0	3	20
Forficula auricularia	1	0	0	0
Sitona lineatus	2	26	39	0
Lumbricus terrestris	0	1	0	0
Formicidae spp.	0	0	7	0
Apocrita spp. (parasitic wasps)	0	10	16	0
Meligethes aeneus	0	29	31	0
Psylliodes chrysocephala	2	0	0	0
Oulema melanopa	2	0	0	0
Tipula spp.	0	1	0	0
Coccinellidae spp.	1	1	0	10

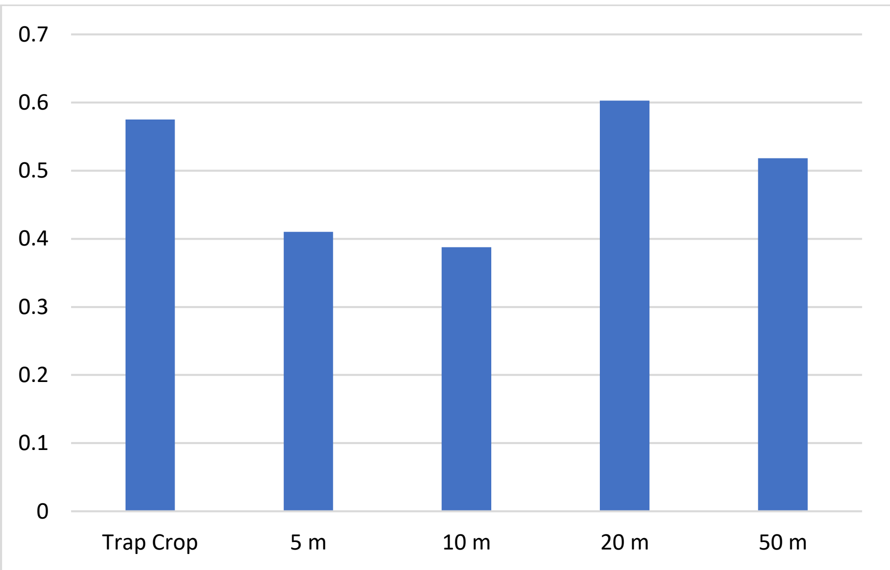

Figure 38: *Simpson Index calculated from all pitfall trap records in field 10 (with lures) at HH for the trap crop area and at 5, 10, 20 and 50 metres from the trap crop in 2021.*

The pitfall traps at HH show the highest level of biodiversity at 20m from the trap crop.

Table 24: *Total number of insects recorded in sweep net samples during June, July and August 2021 in field 9 (without lures) at HH. Where identification to species was not possible, insects were identified to order, family or genus.*

	11/06/2021	22/06/2021	05/07/2021	23/07/2021	03/08/2021
Sitona lineatus	28	14	4	144	542
Bruchus rufimanus	31	6	12	5	1
Hypera spp.	0	1	0	0	0
Chrysopidae spp.	1	0	0	9	2
Meligethes aeneus	2	2	4	4	0
Oedemera spp.	3	0	1	0	0
Acyrthosiphon pisum	9	41	188	203	21
Myzus persicae	0	5	20	33	11
Aphis fabae	0	1	1	0	3
Apocrita spp. (parasitic wasps)	20	56	0	9	0
Diptera spp.	44	50	114	165	79
Syrphidae spp.	0	0	3	1	0
Asilidae spp. (uncertain identification)	0	1	2	0	0
Palomena spp.	0	0	0	3	0
Cicadellidae spp.	1	4	16	28	19
Tipula spp.	2	4	0	0	0
Coccinellidae spp. (adult)	3	0	0	9	4
Coccinellidae spp. (larvae)	0	4	5	2	2
Araneae spp.	0	2	0	1	0
Carabidae spp. (other)	1	0	0	0	0
Lepidoptera spp. (caterpillar)	0	0	2	3	0
Lepidoptera spp.	0	1	0	0	0

Table 25: *Total number of insects recorded in sweep net samples during June, July and August 2021 in field 10 (with lures) at HH. Where identification to species was not possible, insects were identified to order, family or genus.*

	11/06/2021	22/06/2021	05/07/2021	23/07/2021	03/08/2021
Sitona lineatus	37	13	4	147	571
Bruchus rufimanus	32	6	11	4	0
Hypera spp.	1	0	0	0	0
Chrysopidae spp.	1	0	0	0	0
Meligethes aeneus	3	0	0	7	0
Acyrthosiphon pisum	19	38	189	7	8
Myzus persicae	0	4	10	1	0
Apocrita spp. (parasitic wasps)	54	52	0	10	0
Diptera spp.	34	53	137	177	49
Syrphidae spp.	0	0	1	2	5
Asilidae spp. (uncertain identification)	4	0	1	0	0
Palomena spp.	1	0	1	0	1
Cicadellidae spp.	3	6	5	4	14
Tipula spp.	5	3	1	0	0
Coccinellidae spp. (adult)	2	0	0	2	0
Coccinellidae spp. (larvae)	0	0	6	0	0
Araneae spp.	0	0	0	0	1
Lepidoptera spp. (caterpillar)	0	0	0	1	1

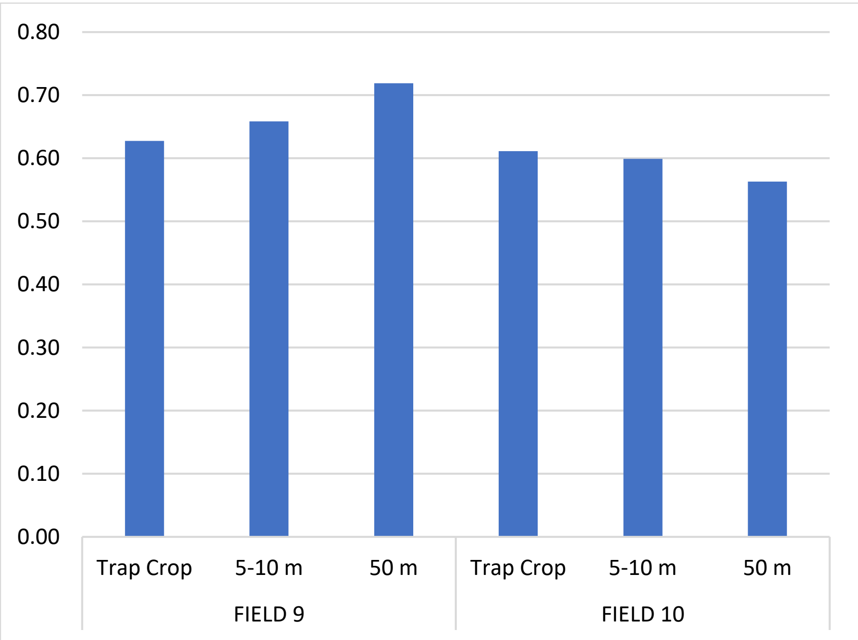

Figure 39: *Simpson Index calculated from all sweep netting records for the trap crop areas, at 5-10 metres and at 50 metres from the trap crop in fields 9 and 10 at HH in 2021.*

Diversity in field 9 was greater in the main crop compared to the trap crop, and in field 10 diversity was greater in the trap crop than the main crop (Figure 39). The early sown spring bean trap crop area in field 9 did not contain plant volatile or pheromone lures.

All sites comparison of pests and beneficial insects

When the proportion of pest species recorded during sweep netting was compared to the proportion of beneficial insects at each site, there appeared to be some differences between the sites (Figures 40 to 42).

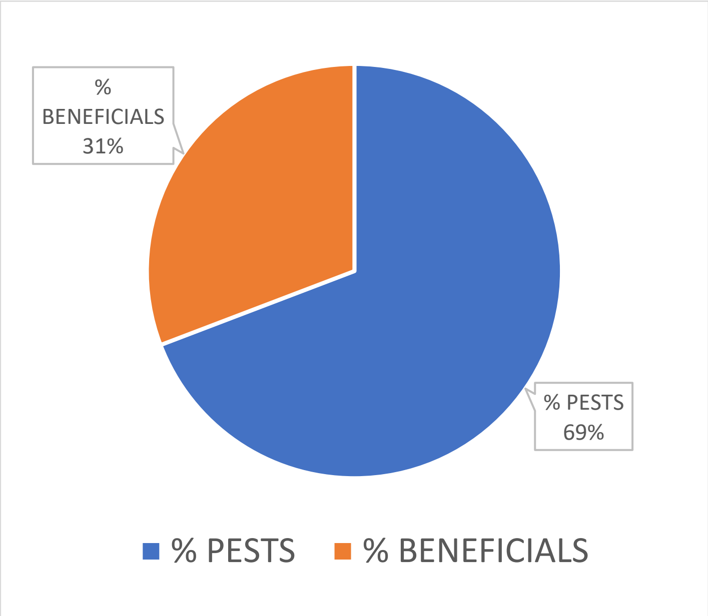

Table 40: *Percentage of pests compared to percentage of beneficial insects recorded at MID during sweep netting in 2021.*

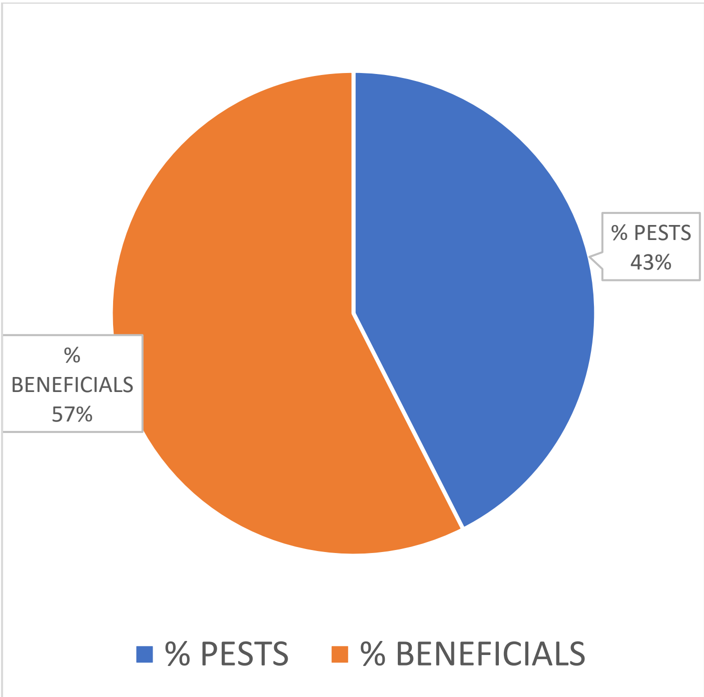

Figure 41: *Percentage of pests compared to percentage of beneficial insects recorded at PAP during sweep netting in 2021.*

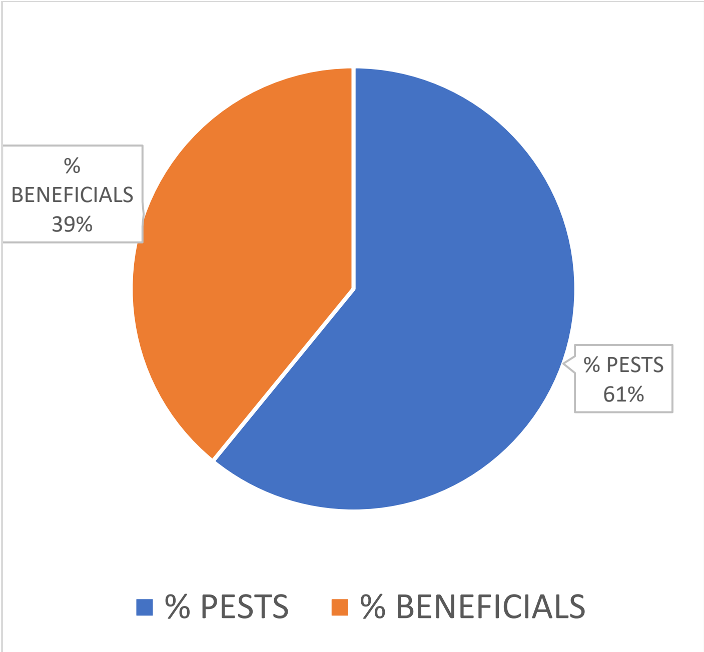

Figure 42: *Percentage of pests compared to percentage of beneficial insects recorded at HH during sweep netting in 2021.*

The percentage of pest species was lower than the percentage of beneficial insects recorded at the farm where a more regenerative farming approach has been taken for the last 10 years. At this farm, no insecticides have been used during this time, whereas at the other two sites, insecticides are used when necessary in the rotation.

Conclusions

There were some significant associations between weevil foliar damage and yield, where higher levels of weevil notching at HH and MID were associated with lower yield. This might be expected, as this could indicate higher levels of weevil larval feeding in the root nodules in these areas. The association between high levels of bruchid beetle damage and lower yield at MID in 2021 is less easy to explain, as bruchid damage does not normally affect yield to such a great degree, unless levels of damage are greater than 50%. The association may be explained by plant density at MID, the areas where yield was lower having lower plant density and potentially higher levels of bruchid damage per plant. This requires further data analysis and evaluation.

There were no clear patterns of damage at MID in 2021, although the area of poorer establishment (lower plant density) also had higher levels of pest damage from both pea and bean weevils and bruchid beetles (Figure 14 to 16, column E). The intensity of pest damage per plant was higher in this area, possibly due to the reduced number of plants available for feeding. Trap crops A and B may have influenced this effect as levels of damage were lower closer to these two areas. Lucerne is known to be a host of pea and bean weevils and therefore it is possible that this helped to retain them in the trap area and away from the main field bean crop. There were no clear effects or patterns observed from emergence trap data, which measured new generation pea and bean weevil emergence following pupation.

At PAP, there were no effects of the trap crop on levels of pest damage across the field in 2021. Pest pressure at PAP was lower overall than the two other sites HH and MID, possibly due to the long-term regenerative approach taken on this farm.

Site HH showed the clearest effect of the trap crop in both study fields (Figures 24 to 29). Pest damage from both pea and bean weevil and bruchid beetle was higher in the trap crop area than in the main crop and this is likely to be linked to earlier plant emergence, flowering and pod formation, providing earlier feeding and reproductive opportunities than the main crop. It is not possible to determine whether the presence of the aggregation pheromone lures contributed to the higher levels of pea and bean weevil damage in field 10, and other landscape factors may have influenced this. Emergence of the new generation of pea and bean weevils following pupation in the soil was higher in the trap crop area than in the main crop in both fields and this was clearer in field 9, with pea and bean weevils recorded in emergence traps declining as distance from the trap crop increased (Figures 32 and 33). There were no significant differences in the level of bruchid beetle damage between fields 9 and 10 at HH, although the trap crop area had higher levels of bruchid beetle damage than the main crop in both fields. Earlier sowing of the trap crop also led to higher yields in both fields.

The number of all insects was recorded from sweep netting and pitfall traps, and no clear patterns have emerged in year 1 of this study. Further study may help to elucidate the influence of the trap crop area on diversity within the main crop. The use of pitfall traps has been reconsidered and the number of insects recorded will be undertaken multiple times each year, but over a shorter period than two weeks each time to allow better preservation of samples.

The percentage of pest species compared to beneficials was lower at PAP in 2021, whereas at MID and HH the proportion of pests was greater than that of beneficial insects. This may be associated with the different farming system at PAP, where a regenerative approach is taken, and no insecticides are used in the farm. At HH and MID, insecticides are used within the arable rotation when necessary, although not in 2021.

Trials will be repeated in 2022 and 2023, and a greater number of trials will be carried out at HH to examine further the effects of the early sown spring bean trap crop. The trial at PAP will be repeated. Unreplicated plots have been established at a demonstration site in Cambridgeshire to allow discussion and exchange of ideas with growers. A more comprehensive plot trial will be established in 2022 and early 2023 to allow results of the work to be demonstrated to growers during the 2023 season. This will ensure further results from 2022 trials are integrated into the discussions.

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Appendix A

Methods:

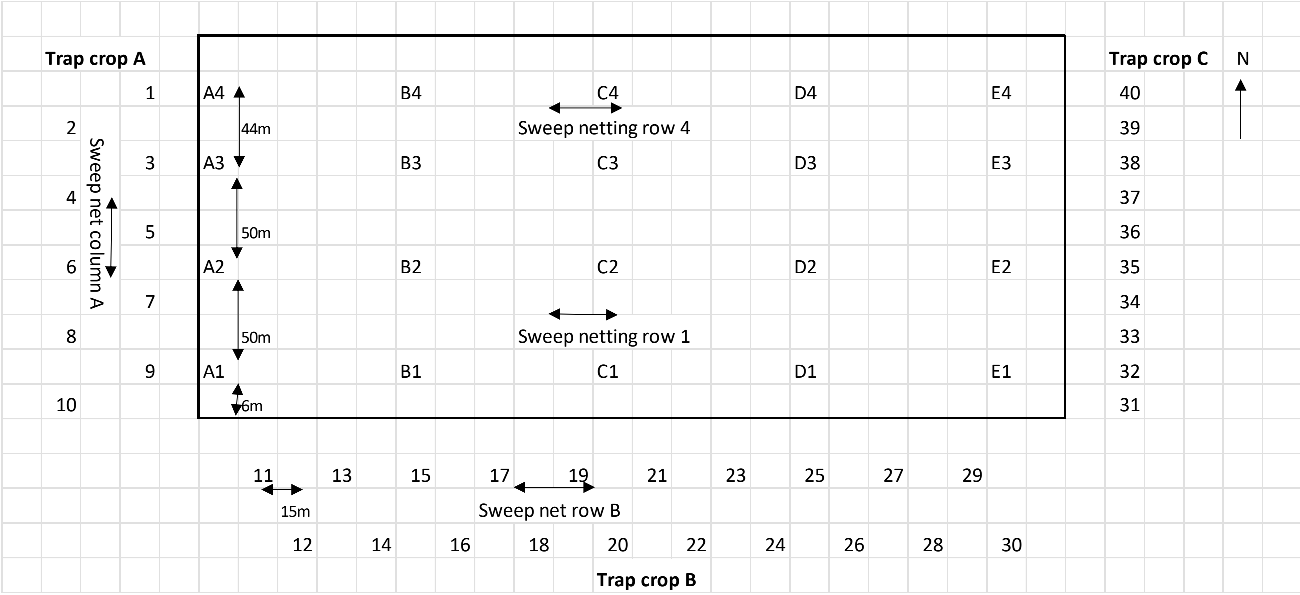

Figure I: *Location of sample points, traps and sweep net transects at MID in 2021. Weevil and bruchid traps were located 15 metres apart in trap crops A and B in parallel lines 10m apart, and in a straight line in trap crop C. Sweep netting was carried out along parallel lines of 25m length.*

Table I: *Location of traps and sweep net transects at MID in 2021. See Figure I.*

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			

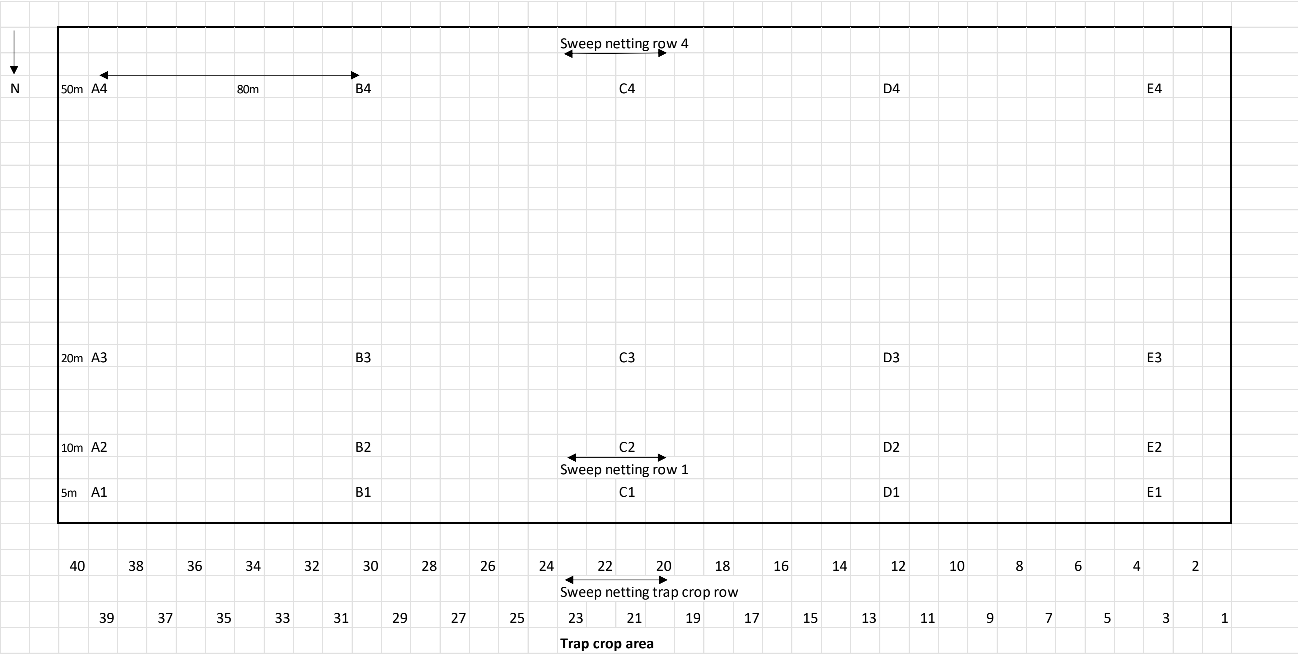

Figure II: *Location of sample points, traps and sweep net transects in the trap crop field at PAP in 2021. Weevil and bruchid traps were located 12 metres apart in the trap crop in parallel lines 10m apart. Sweep netting was carried out along parallel lines of 25m length.*

Table II: *Location of traps and sweep net transects at PAP in 2021. See Figure II.*

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			

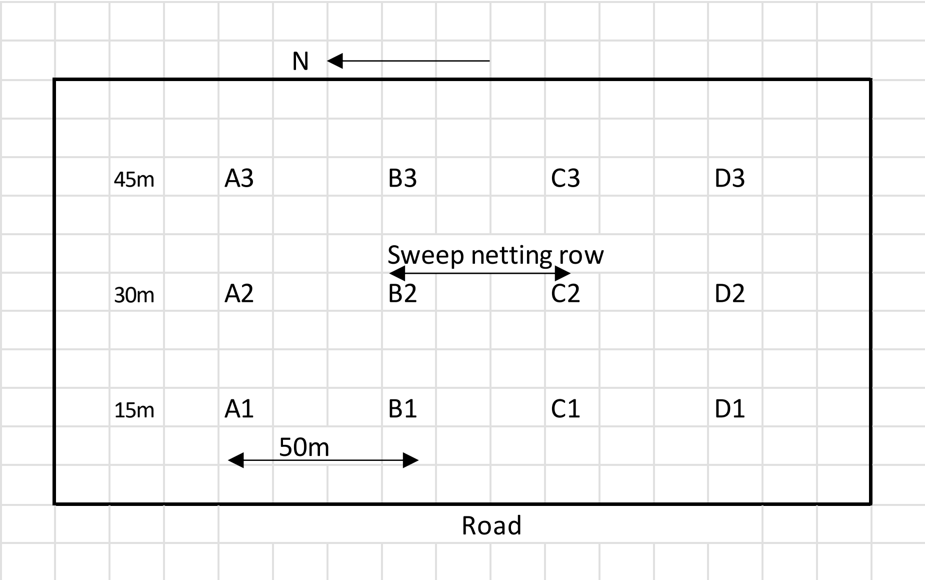

Figure III: *Location of sample points and sweep net transects in Hedge field at PAP in 2021.*

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

Sweep Netting	Emergence traps
Centre row	B1
	B2
	B3

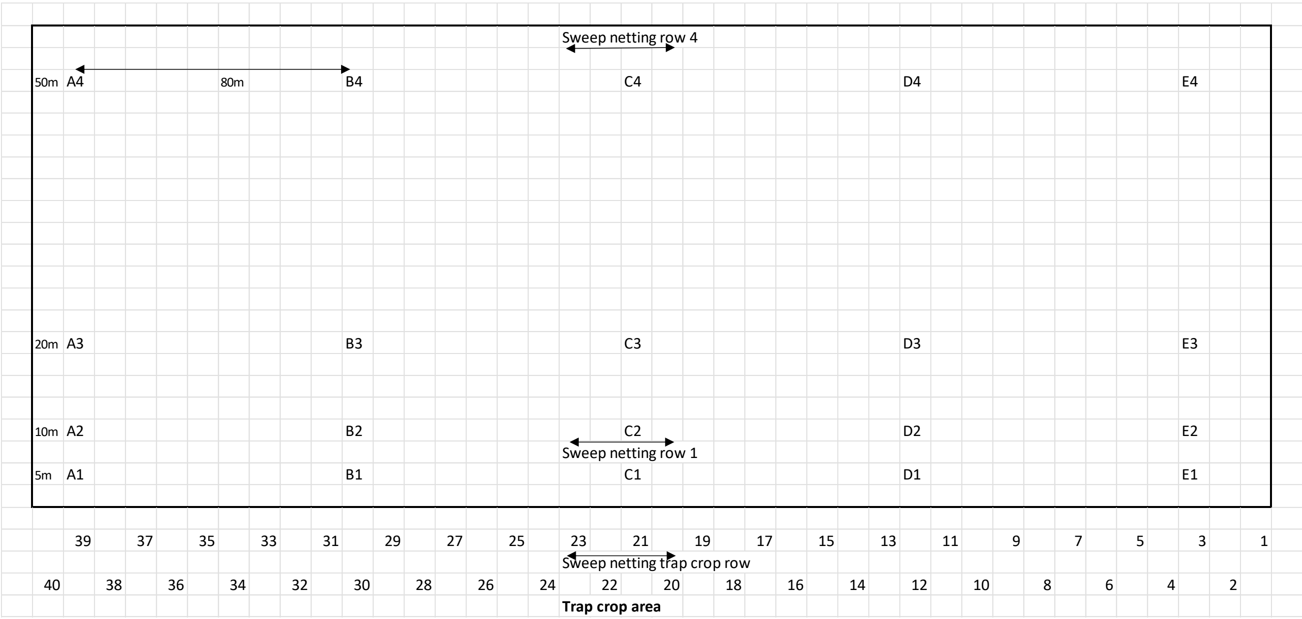

Figure IV: *Location of sample points, traps and sweep net transects at HH fields 9 and 10 in 2021. Weevil and bruchid traps were located 12 metres apart in the trap crop in parallel lines 10m apart in field 10 only. Sweep netting was carried out along parallel transects of 25m length.*

Table IV: *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 V: *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 B

Figure IV: *Details of wild bird mixture used at MID under the UK Higher Level Stewardship. Linseed was added to the mixture when it was sown, and lucerne was drilled into the trap crop area in July 2020.*