Aphid Control in Organic Pea and Cole Crop Production

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EXECUTIVE SUMMARY

Pea aphids (*Acyrthosiphon pisum*) and cabbage aphids (*Brevicoryne brassicae*) are major pests of peas and cole crops respectively and few effective control tools are available for organic production. Heavy aphid infestations cause severe economic losses for two main reasons - reduce crop yield and crop contamination for processing or fresh market. The objective of this study was to examine the efficacy of potential biological, physical and chemical control tools for aphid management in organic pea and cole crops. Firstly, we evaluated the efficacy of augmentative releases of the predatory midge *Aphidoletes aphidimyza* (Aphidoletes) with and without the added food resources provided by insectary plants for pea aphid control in peas. Secondly, we evaluated the potential of two types of row covers - Agryl P17 (Fiberweb Inc.) and Protecknet (Dubois Agrinovation, QC) compared with the industry standard of Soap sprays and an untreated Control for cabbage aphid control. Finally, we evaluate the efficacy of three organic insecticides for aphid control in peas and cole crops 1) Botanigard (Laverlam International Corp.), 2) Purespray Green (Petro Canada) and 3) Influence (AEF Global Inc.) against the industry standard 4) Soap (cole crops) and 5) a water only Control. All of our trials were conducted in agricultural fields during the 2010 field season. The main findings from these trials were as follows.

- We did not observe any impact of Aphidoletes releases on pea aphids nor did we find any Aphidoletes larvae (released or native) on peas in the weeks following release. Further, the insectary plants that were provided did not support increased activity of Aphidoletes or other naturally occurring enemies (e.g. ladybugs, syrphids, parasitoid wasps). Higher release rates than those used in our field trials may be needed in order to obtain aphid control. Also higher densities of insectary plants may provide better attraction and retention of natural enemies in fields, at the beginning of the season.

- We found that both types of row covers were equally effective at keeping aphids off of the crop and overall provided more consistent and longer duration of aphid control than Soap, which provided inconsistent control. We also saw that the row covers could be effective at excluding caterpillars from the crop as well.

- In both peas and cole crops we observed efficacy of products when the pre-treatment aphid counts were quite low (i.e. < 30 aphids/plot in peas and < 10 aphids/plot in cole crops). Under these starting conditions the two products that were consistently effective were Purespray and Influence. However, in the cole crop trials neither product was significantly more effective than Soap which is cheaper product choice.

INTRODUCTION

Aphids are a major pest in organic vegetable production. Heavy aphid infestations cause severe economic losses for two main reasons - reduce crop yield and crop contamination for processing or fresh market. Cabbage aphids (*Brevicoryne brassicae*) are the main problem for cole crops and organic production usually requires weekly application of insecticidal soap. However, once cabbage aphid colonies are established, soap provides inconsistent control due to poor product coverage on plants. Peas are another crop widely affected by aphids. Pea aphid (*Acyrthosiphon pisum*) infestations often result in economic losses due to contamination of the crop. While conventional pea growers have several insecticides that can be used against aphids (e.g. dimethoate, malathion and lambda-cyhalothrin) (LMHIA 2009)), there are no aphid control protocols specifically for organic production For both peas and cole crops there are biological, physical and chemical control options that could be implemented for organic aphid control.

Biological control performed by naturally occurring populations of predators and parasitoids can have considerable impacts on aphid populations (Smith and Chaney 2007, Schmidt *et al*. 2004, Bowie *et al.* 1999), but the timing of this control is unpredictable. Natural enemies do not always arrive early enough in the season to slow aphid population growth (Nieto *et al.* 2006). Targeted release of beneficials (augmentative release) may be a more effective strategy for using biological control for aphids in vegetable crops - this approach is widely used in greenhouse vegetable production (Rabasse and van Steenis 1999, Zehnder *et al.* 2007) but is less common for field-grown vegetables. The predatory midge *Aphidoletes aphidimyza* (Aphidoletes) is a commercially available aphid predator. A field study done on pepper crop showed the efficacy of *A. aphidimyza* (two releases of two-three midges/plant, 21 days apart) at keeping the green peach aphids population significantly lower than the untreated control (Meadow *et al*. 1985). Providing natural enemies with food - pollen and nectar in the case of aphid predators and parasitoids - can further improve biological control by either introduced or naturally occurring enemies (Landis *et al.* 2000). Robinson *et al*. (2008) showed that providing flowers increased egg production by aphid predators, when aphid populations were low. Plants such as dill and alyssum attract beneficial insects and provide pollen and nectar (Hickman *et al*. 1995, Colley and Luna 2000) which can help enemies to establish earlier in the vegetable field. These "insectary" plants can be planted directly into the field or in pots. Used in combination, augmentative release and insectary plants could help to provide the early control of aphids needed to prevent economic losses.

Physical control is another interesting option for aphid control in organic production. Physical control using barriers to prevent insect pests from accessing crops have been developed using various types of nets, meshes, and row cover materials (Vincent *et al.* 2003). Two types of row covers currently available to Canadian growers for insect exclusion are Agryl P17 (17g/m^2), a lightweight woven polypropylene fabric and

Protecknet ultimate (120 g/m²), high density polyethylene mesh. A field experiment conducted on lettuce showed that using row covers (polypropylene type) significantly reduced aphid and tarnished plant bug populations and significantly reduced crop damages compared to the uncovered control (Rekika *et al.* 2009). Similarly, using row covers on carrot plants reduced damage caused by carrot weevil by 65-75% (Rekika and Stewart 2008). Some of the potential limitations of physical control however include the increased labour to install and remove the barriers, increase in other pest issues (e.g. weeds or disease), and disposal or storage.

Finally, chemical controls (insecticides) suitable for organic production (e.g. OMRI approved) continue to be practical and cost-effective solutions for many pests. Organic insecticides containing fungi or bacteria (entomopathogens) and botanical extracts are increasingly available in Canada. Botanigard (Laverlam International Corp) is a recently registered product (for greenhouse use) that contains the fungus *Beauveria bassiana* a naturally-occurring pathogen of many insects including aphids. Formulations of *B. bassiana* caused up to 86 % mortality of aphids on canola (Miranpuri and Khachatourians 1993). Products derived from garlic extracts have been shown to have both insecticidal and repellent effects on aphids and other agriculturally important pests (Prowse *et al.* 2006). In recent research, plant lectins purified from cultivated garlic bulbs (*Allium sativum*) have been shown to cause a significant reduction on the survival of first-instar pea aphids (Sadeghi *et al*. 2009). Influence (AEF Global Inc.) is a garlic-based pesticide currently under review by the Pest Management Regulatory Authority (PMRA). Finally, mineral oils have also been shown to control aphids and other arthropods. For example, application of mineral oil on aphid eggs resulted in a 75 % reduction of aphid population growth (Iversen and Harding 2007). Purespray (Petro Canada) is a mineral oil that is currently approved for organic production in the US, and is being considered for registration in Canada (M. Fefer, Petro Canada, personal communication, 2009). Purespray formulations are fairly broad spectrum, Stansly and Conner (2005) found that Purespray suppressed whitefly, broad mites and aphids on field-grown tomato and pepper in Florida. Similarly, most studies with other types of horticultural oils show good suppression of different aphid species (Kraiss and Cullen 2008a, Najar-Rodriguez 2007, Fernandez *et al.* 2005).

The objective of this study was to examine the efficacy of potential biological, physical and chemical control tools for aphid management in organic pea and cole crop production.

MATERIALS AND METHODS

Biological Control (Aphidoletes and Insectary Plants for Pea Aphid Control in Peas)

Study Site: The trial was conducted in three organic pea fields in Delta, BC. Planting and weed control was done by the grower. There were no insect or disease control activities in any of the fields. Varieties used were Ice Breaker (Field 1) a processing variety and Paladio (Field 2 and 3) a fresh market variety. No artificial irrigation was used. Field 1 was planted on April 05, Field 2 on April 18 and Field 3 on May 03. In each field, crop emergence was on average 10-14 days from planting. Natural infestation of aphids was monitored weekly from crop emergence.

Treatment Description and Plot Layout: Each field was divided into three equal sized sections (Appendix I and Table 1), and section size varied from field to field. In order to evaluated the efficacy of the predatory midge *Aphidoletes aphidimyza* (Aphidoletes) with and without the added food resources provided by insectary plants the trial examined three treatments 1) Control 2) Aphidoletes release only 3) Aphidoletes release + Insectary plants. Each treatment was randomly assigned to one section in each field. Thus each treatment was replicated three times (1X/field) and there was no replication of treatments within a field.

Aphidoletes were purchased from Evergro/Westgro (Delta, BC). As per the recommendations for greenhouse use, aphidoletes releases started as soon as pea aphids were observed in each field (R. McAdams, Evergro/Westgro, personal communication, 2010). Aphidoletes were release at an average rate of 3000/acre/week for three consecutive weeks. Depending on supply in some weeks the release rate was a bit lower or higher than 3,000 (Table 1). Aphidoletes were shipped as pupae in batches of 1000 pupae/container. Pupae were subdivided into containers with approximately 250 pupae/container. As adults emerged they were kept in the containers for 24 hrs in order to allow adults to mate. Containers were then set out in the assigned sections (Aphidoletes and Aphidoletes + Insectary plants) in each field by placing the containers in the middle of rows amongst plants. Aphidoletes are known to disperse 30 to 45 m from release points (Schelt and Mulder 2000). Container lids were left half open in order to allow flies to leave containers but prevent rainfall from entering. Release was done at dusk as recommended by the supplier.

Table 1. Trial details for Aphidoletes releases and weather conditions for each release done in three organic pea fields.

Field	Section size (acre)	Aphidoletes release date	# Aphidoletes released	Weather conditions on release day
1	0.25	May 23	800	14^{o}C, rain
1	0.25	June 2	1000	13.6^{o}C, cloudy
1	0.25	June 6	750	15.1^{o}C, partly cloudy
2	0.7	May 23	2200	14^{o}C, rain

2	0.7	June 2	1000	13.6 C, windy cloudy
2	0.7	June 6	3750	15.1^{o}C, partly cloudy
3	0.9	June 6	3000	15.1^{o}C, partly cloudy
3	0.9	June 13	3000	16^{o}C, windy clear
3	0.9	June 20	3000	14^{o}C, clear

The insectary planters were planted on April 23 and each 12-gallon pot consisted of 10 *Alyssum*, two carrot (*Daucus carota*), and a single plant of each of the following: phacelia (*Phacelia tanacetifolia*), yarrow (*Achillea filipendulina*), *Coreopsis,* dill (*Anethum graveolens)* and *Rhudbeckia* (Fig. 1). Planters were kept at the Kwantlen Polytechnical University (Langley, BC) greenhouse, under artificial day length, in order to induce flowering prior to placing field. Planters were placed in the Aphidoletes + Insectary planter section of each field at a density of 6 planters/acre prior to the first Aphidoletes release. We chose this density based on the availability of healthy planters with abundantly flowering plants at the start of the trial. So two banker plants were placed in Field 1, four in Field 2 and five in Field 3. Planters were placed out in fields on May 19 (Field 1 and 2) and June 04 (Field 3). Insectary planters were checked every three days and were watered as needed.

Figure 1. Flowering insectary plants were placed in fields at a density of 6/acre.

Assessment and Analysis: One pre-release (two days prior to the first Aphidoletes release) and six post release assessments were done weekly in each field. Post release counts were started approximately one week after the first release. The assessment consisted of recording the number of aphids, Aphidoletes and any other beneficial insects from 50 plants per section. In the Aphidoletes + Insectary planter treatment samples were taken 2 m from the planters. Data (aphids, parasitized aphids, and beneficials) were analyzed using one-way repeated measures MANOVA (Jmp-In 5.1, SAS Institute).

Physical Control (Row Cover in Cole Crops)

Study Site and Maintenance: The trial was conducted in one organic broccoli field (var. Greenbelt) and two organic cabbage (var. Charmant) fields located in Delta, BC. Field 1 (broccoli) was transplanted on May 17, 2010, each bed having three rows of broccoli. Field 2 (cabbage) was transplanted on June 24 and Field 3 (cabbage) on July 13. Cabbages were also grown in beds with two rows of cabbage/bed. Planting and crop management (pest control, fertilizer and irrigation) was done by growers. The trial area and one buffer bed on each side were left untreated when growers had to apply insecticide (Soap). Buffer beds were sprayed with Soap via backpack sprayer by E.S. Cropconsult crew on the same day that the grower sprayed. This step was taken in order to limit damage to the crop but also minimize drift to the trial area. However, in Field 2 and 3, Entrust (ENTRUST 80 W) was sprayed by the grower on July 31 (Field 2) and August 27 (Field 2-3) over the trial area and buffers, in order to control caterpillars and crucifer flea beetles. Hand weeding of the plots was done by E.S. Cropconsult crew once in Field 1 (June 30), once in Field 2 (July 23) and twice in Field 3 (August 02 and 20).

Treatment Description and Plot Layout: Two types of row covers were evaluated in this trial - Agryl P17 (Fiberweb Inc.) and Protecknet (Dubois Agrinovation, QC). The two row cover treatments were compared against the industry standard of Soap sprays and an untreated Control. Each of the four treatments was replicated six times for a total of 24 treatments. Treatments were assigned to plots following a completely randomized designed. Plots were 3 m long X 1.5m or 1 bed wide in broccoli and 3 m long X 1 m or 1 bed wide in cabbage. In each field, all plots were laid out in a single bed (Appendix II) and within the bed plots were separated from each other by a 1 m buffer.

Row cover plots were covered within six days of transplanting. For Protecknet plots, two plastic hoops were used to support the row cover, following the distributors recommendation. Agryl P17 was laid over plots and both Agryl P17 and Protecknet covers were buried along the edges of each plot (Fig. 2). Prior to covering plots with row covers, all plants from all plots were carefully monitored to ensure that there were no insects on plants that would have been trapped under the row cover. Soap was applied following the spray schedule recommended to the grower (when cabbage aphids were above threshold in the field) (Table 2). Soap was applied at a dilution of 1 part of soap for 50 parts of water, at a rate of 600L/acre applied with a backpack sprayer. This resulted in 0.42 L and 0.63 L of spray volume applied to the cabbage and broccoli Soap plots/spray, respectively.

Figure 2. Protecknet (top left) and Agryl P17 (top right) were tested for cabbage aphid control along side Soap (blue flags) and an uncovered Control (pink flags) as seen in the overall view (bottom).

Table 2. Soap application dates in the row cover trial in the three fields. Soap was applied when cabbage aphids were above threshold in the surrounding field

Field	Spray dates for Soap plots
Field 1 (broccoli)	June 25, July 2, 8
Field 2 (cabbage)	July 16, 23, 29 August 3,10, 13, 20, 23, 27, 30

	September 3, 8
Field 3 (cabbage)	July 30, August 6, 13, 20, 23, 27, 30 September 3, 8, 15, 22, 29

Assessment and Analysis: The number of aphids, caterpillars and beneficial insects were recorded weekly from five plants located in the middle of each plot. Field 1 was assessed seven times from May 28 to July 12, Field 2 was assessed 10 times from July 5 to September 8, and Field 3 was also assessed 10 times from July 26 to September 29. At harvest, the heads from the middle five plants were cut and weighted to assess yield. Weekly insect assessment data were analyzed using repeated measures MANOVA, and harvest data were analyzed using one way ANOVA. *Post hoc* means comparisons were done using Tukey Kramer HSD ($\alpha = 0.05$) (Jmp-In 5.1, SAS Institute).

Chemical Control (Spray Trial in Peas)

Study site: The trial was conducted in the same three organic pea fields that were used for the Biological Control trial in Delta, BC (see above for field details). Plots for the chemical control trial were located on the West side of Field 1, North side of Field 2 and West side of Field 3, and were separated from the Biological Control trial by a few meters (Appendix I). Fields were monitored weekly from emergence for natural infestation of aphids.

Treatment Description and Plot Layout: In order to evaluate the efficacy of organic insecticides for aphid control in peas, the trial examined three possible solutions 1) Botanigard, 2) Purespray 3) Influence along with a water only Control (Table 3). Each of the four treatments was replicated six times, for a total of 24 plots/field. Treatments were randomly assigned to plots resulting in a completely randomized designed. Plots were 2 m long and 1 m wide and were separated by 0.5 m buffer. Plots were laid on a 2 X 12 grid in Field 1 and a 3 X 8 grid in Fields 2 and 3 (Appendix I).

Treatments began when aphids started to appear, and when weather conditions allowed for sprays. Plots were sprayed weekly, from June 07 to July 06, for a total of five applications. Treatments were applied with a backpack sprayer hand-pumped to maintain full pressure. Treatments were applied either in the early morning or late afternoon. As per the product labels, plants were sprayed to allow good coverage but to avoid run-off (0.2 L of spray solution/plot).

Table 3. Description of the three products evaluated against the water Control for aphid control in organic peas.

Trade Name and Manufacturer	Active Ingredient	Rate	Amount of product/plot

Botanigard (Laverlam International)	*Beauveria bassiana*	500g/400 L water	0.25 g
Purespray Green (Petro Canada)	Paraffinic oil	1% solution	2 mL
Influence (AEF Global Inc.)	Garlic Extract	5% solution	10 mL
Water			0.2 L

Assessment and Analysis: One pre-treatment count (June 3 or 4) and five post treatment counts were conducted in each field (June 10 to July 9). The number of aphids was recorded from 10 plants/plot. All data were analyzed with repeated measures MANOVA (Jmp-In 5.1, SAS Institute).

Chemical Control (Spray Trials in Cole Crops)

Study site: The trial was conducted in two organic broccoli (var. Greenbelt) fields (Field 1 and 3) and in an organic cabbage (var. Charmant) field (Field 2). Fields were located in Delta, BC. The broccoli fields were transplanted on May 17 and each bed had three rows of broccoli. The cabbage field was transplanted on June 24 and each bed had two rows of cabbage. Planting and crop management (pest control, fertilizer and irrigation) were done by each grower. The trial area and a buffer bed on each side were left untreated when growers had to apply insecticide. On those buffer beds, insecticides were applied with a backpack sprayer by E.S. Cropconsult crew to limit damage to the crop and drift to the trial area. In the cabbage field, Entrust (ENTRUST 80 W) was sprayed by the grower over the trial area on July 31 and August 27, in order to minimise the damage to the crop caused by caterpillars and crucifer flea beetles. Hand weeding of the plots was done by E.S. Cropconsult crew once in the cabbage field on July 23.

Pest inoculation: Fields were monitored weekly from transplanting for natural infestation of cabbage aphids. Natural infestation occurred in the plots in the cabbage field (Field 2). Natural infestation also occurred in the broccoli plots (Field 1 and 3) but the distribution of cabbage aphids was not even within the trial areas in Field 1, therefore broccoli plots in that field were inoculated with cabbage aphids on June 30. Inoculation was done by collecting colonies of cabbage aphids from the same fields and placing a piece of leaf containing about 40 aphids on each of the three middle plants in each plot (total of 120 aphids/plot). These plants were the same plants used for assessment (see below).

Treatment Description and Plot Layout: In order to evaluate the efficacy of organic insecticides for aphid control in cole crops, the trial examined three possible solutions 1) Botanigard, 2) Purespray, 3) Influence against the industry standard 4) Soap and 5) a water only Control (Table 4). Each of the five treatments was replicated six times (for a total of 30 replicates/field). Treatments were randomly assigned to plots for a completely randomized design. Plots were 1m long X 1 m wide (cabbage) and 1 m long X 1.5 m wide (broccoli). Plots were separated by 0.5 m buffer. All plots were laid out in a single bed (1 X 30 grid) (Appendix III).

Plots were sprayed weekly, for a total of six sprays in Field 1 (July 2 to July 30) and Field 2 (July 16 to August 20) and five sprays in Field 3 (July 30 to August 27). Sprays were applied in the early morning or late afternoon. Treatments were applied with a backpack sprayer and plants were sprayed to allow good coverage but to avoid run-off (0.2 L of spray solution for broccoli plants and 0.14 L of spray solution for cabbage plants).

Table 4. Description of the three products evaluated against Soap and the water Control for aphid control in organic cole crops.

Trade Name and Manufacturer	Active Ingredient	Rate	Broccoli-Amount of product/plot	Cabbage-Amount of product/plot
Botanigard (Laverlam International)	*Beauveria bassiana*	500g/400 L water	0.26 g	0.13 g
Purespray Green (Petro Canada)	Paraffinic oil	1% solution	2.1 mL	1.4 mL
Influence (AEF Global Inc.)	Garlic Extract	5% solution	10.5 mL	7 mL
Soap (Woodstream Canada Corporation)	Potassium salts of fatty acids	2% solution	4.2 ml	2.8 mL
Water			0.21 L	0.14 L

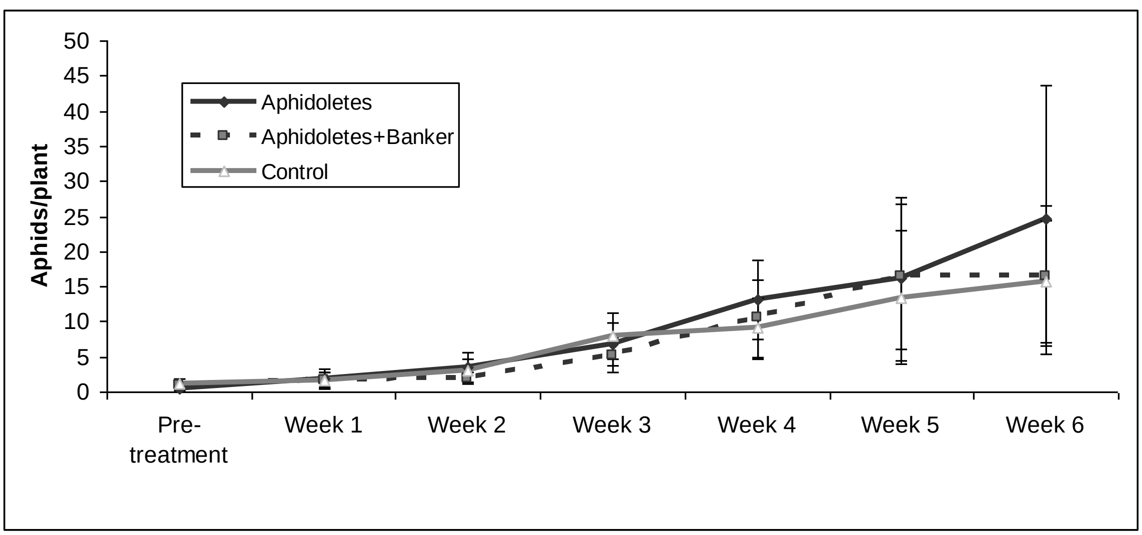
Assessment and Analysis: One pre- treatment count and six (Field 1 and 2) or five (Field 3) post-treatment were conducted. Field 1 counts were done on July 2 (pre) and weekly from July 5 to August 9. Field 2 counts were done on July 16 (pre) and weekly from July 20 to August 30. Finally, Field 3 counts were done on July 30 (pre) and weekly from August 2 to 30. The number of aphids, caterpillars and beneficial insects were recorded weekly from three plants located in the middle of each plots. Yield was assessed in the cabbage field (Field 2) on September 15, in order to evaluate the effects of treatments on plant performance. All data were analyzed with repeated measures MANOVA (Jmp-In 5.1, SAS Institute).

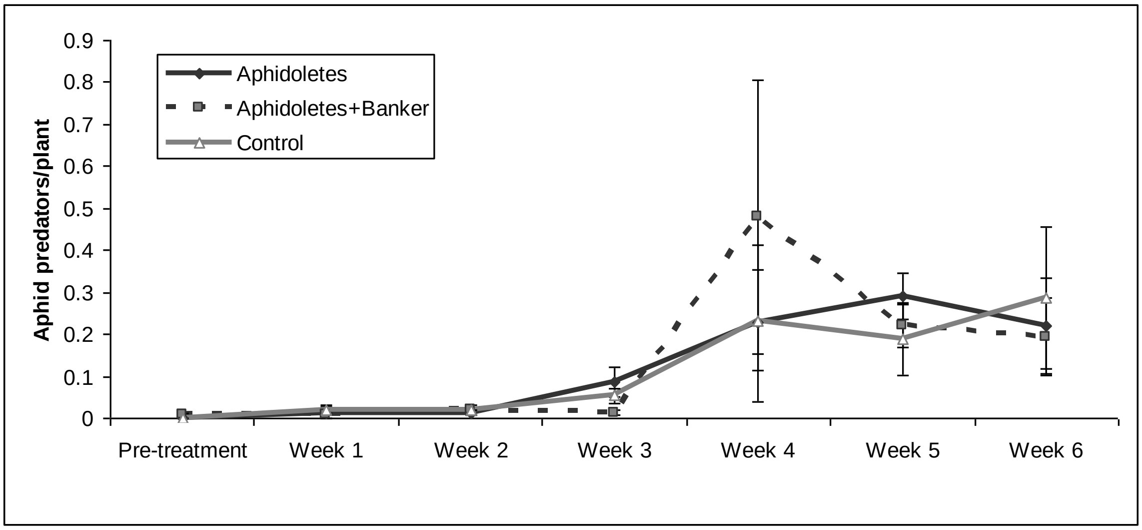
RESULTS

Biological Control (Aphidoletes and Banker Plants in Peas)

Data from all three fields were pooled, as there were not enough replicates/field to determine if there were any significant field effects. There were no significant effects of Aphidoletes release or the combination of Aphidoletes release + Insectary plants on the number of pea aphids on plants over the six weeks of the study (Fig. 3a; Treatment: F (2,6) = 0.058, P = 0.94; Time: F (6,1) = 0.78, P = 0.69; Time X Treatment: F (12,2) = 0.57, P = 0.78). Also, we found no Aphidoletes larvae in any of the plots; however this may not be surprising given that only 50 plants were searched/section/week. We used 50 plants/section as our assessment level based on monitoring methods used for field peas in other areas (http://pestbulletin.wi.gov/pests.jsp?categoryid=6&issueid=82), but for the purposes of the trial more intensive monitoring may have been needed in order to detect Aphidolotes larvae. However, in previous years, Aphidoletes larvae were observed on heavily infested pea plants based on random examination of fewer than 20 plants in a field (E.S. Cropconsult Ltd., unpublished data). Also, we did observe naturally occurring populations of syrphid larvae, ladybug larvae and adults on the 50 pea plants searched/ section/week.

One possible effect of insectary plants could have been more naturally occurring aphid predators in the sections of fields with insectary plants, as the flowers would provide an early in-field source of pollen and nectar that adult syrphids and ladybugs need to support reproduction. However we found no difference among the three treatments in the number of aphid predators/plant (Fig. 3b; Treatment: F (2,6) = 0.05, P = 0.95, Time: F (6,1) = 10.95, P = 0.23; Time X Treatment: F (12,2) = 0.36, P = 0.90). Nor was there any effect of insectary plants on the number of parasitized aphids (mummies) observed on peas (Fig. 3c; Treatment: F (2,6) = 0.04, P = 0.96, Time: F (6,1) = 1.54, P = 0.55; Time X Treatment: F (12,2) = 0.52, P = 0.81).





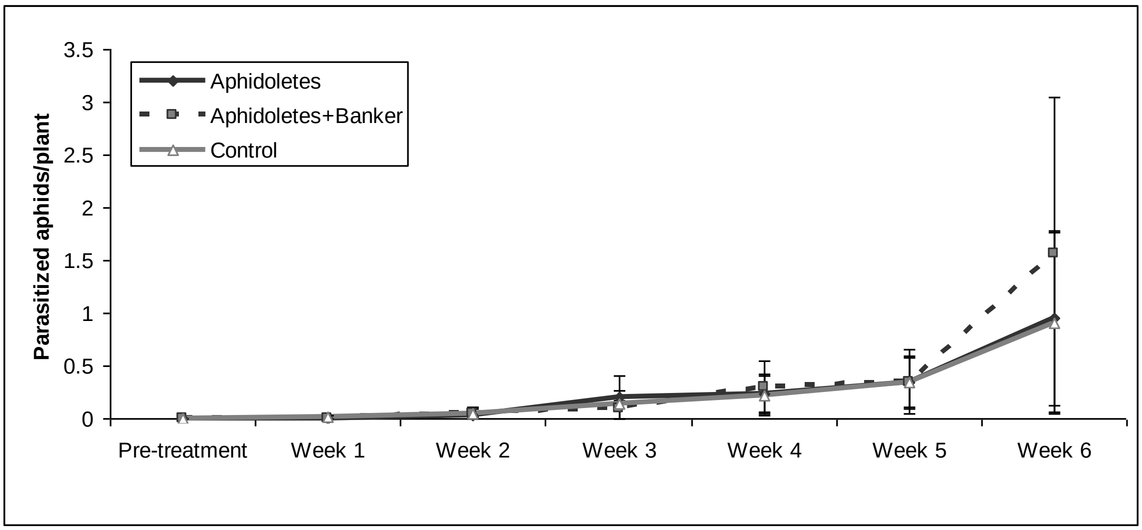


Figure 3. Effect of augmentative Aphidoletes release alone and in combination with Insectary plants on a) aphids, b) naturally occurring aphid predators and c) parasitized aphids observed on pea plants. Each point represents the mean ± s.e. of three replicates/treatment (total N = 9).

Physical Control (Row Cover in Cole Crops)

Effect of field - There were significant differences in the aphid populations in the three fields over the course of the trial (Field: F (2,69) = 0.62, P = 0.54 Time: F (6,64) = 5.53, P = 0.0001; Field X Time: F (12, 128) = 3.58, P = 0.0001). All fields started with low aphid levels, however populations started to build up earlier in Field 2 than in Field 1 or 3. The effect of treatments on aphid, natural enemy and caterpillar populations was analyzed separately for each field.

Treatment Effects (Field 1) - There was no significant effect of row cover treatment on aphid levels in Field 1 (Fig 4.; Treatment: F (3,20) = 0.88, P = 0.47; Treatment X Time: F (18, 42) = 0.65, P =0.84). Aphid levels were low overall in this field and thus there was no significant increase over time (Time: F (6,15) = 0.86, P = 0.55). The only exception to this was a single Protecknet plot that had very high aphid infestations in the last two weeks of the trial (Fig. 4). The reason for this was that one end of the Protecknet had become dislodged from the soil and lifted up, exposing plants for several days before the cover could be reburied. We think that aphids were able to get into this one plot during the time that the Protecknet was not properly maintained. In addition to no effect on aphids, the row cover treatments had no significant effects on either the number of aphid predators (Treatment: F (3,20) = 1.44, P = 0.26; Time: F (6,15) = 0.54, P = 0.77; Treatment X Time: F (18, 42) = 0.50, P = 0.94) or caterpillars (Treatment: F (3,20) = 0.78, P = 0.52; Time: F (6,15) = 2.59, P = 0.06; Treatment X Time: F (18, 42) = 1.67, P = 0.08) found in plots. Finally, yield was significantly higher in Agryl P17 plots than the Control or Soap plots, Protecktnet did not cause significant differences in yield compared to the Control or Soap (Fig. 5; Treatment: F (3,20) = 6.11, P = 0.004). Agryl P17 does increase the temperature under covers (Rekika *et al.* 2009) and this may explain the higher yield in Agryl plots. In contrast, the Protecktnet cover does not cause an increase in temperature (E.S. Cropconsult Ltd. unpublished data).

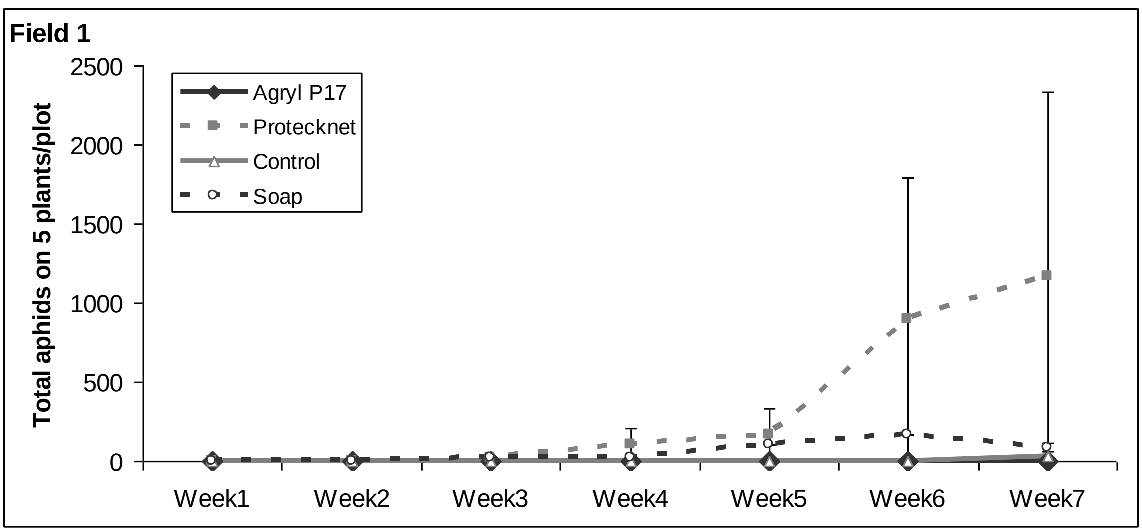


Figure 4. Effect of two types of row cover and industry standard treatment of Soap on cabbage aphid infestation in cole crops (broccoli). Each point represents the mean ± s.e. of six replicates/treatment (total N = 24).

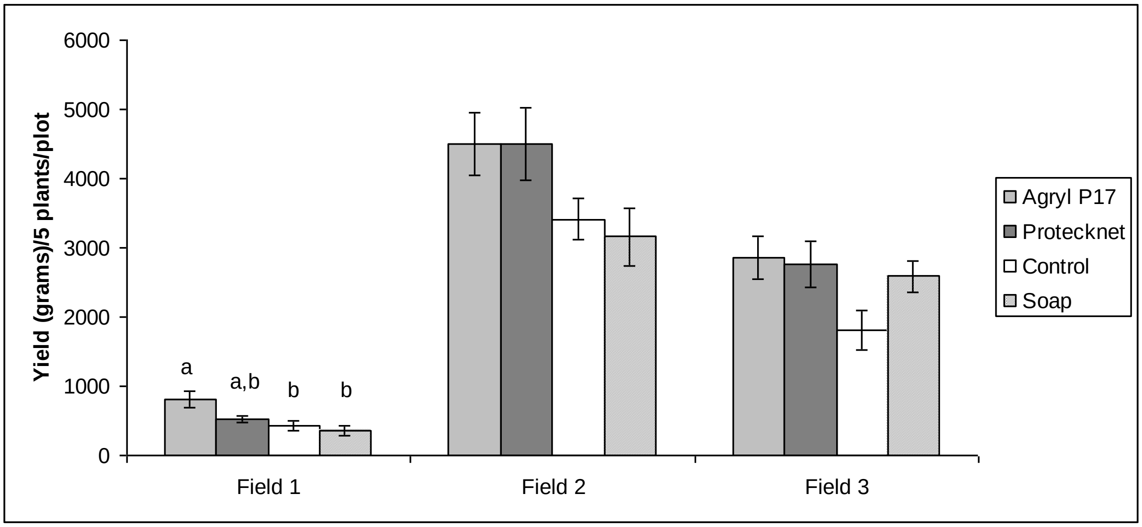
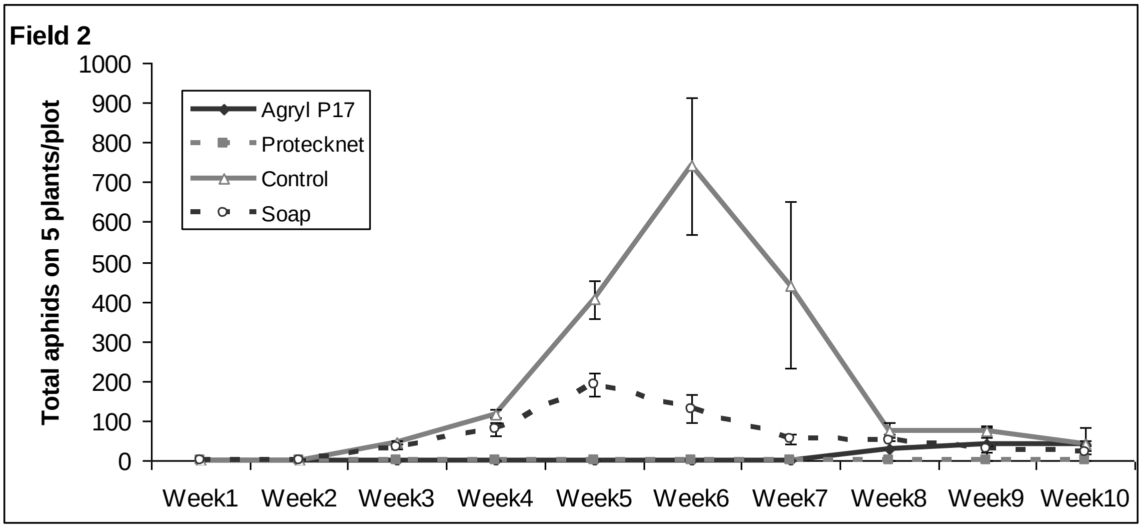
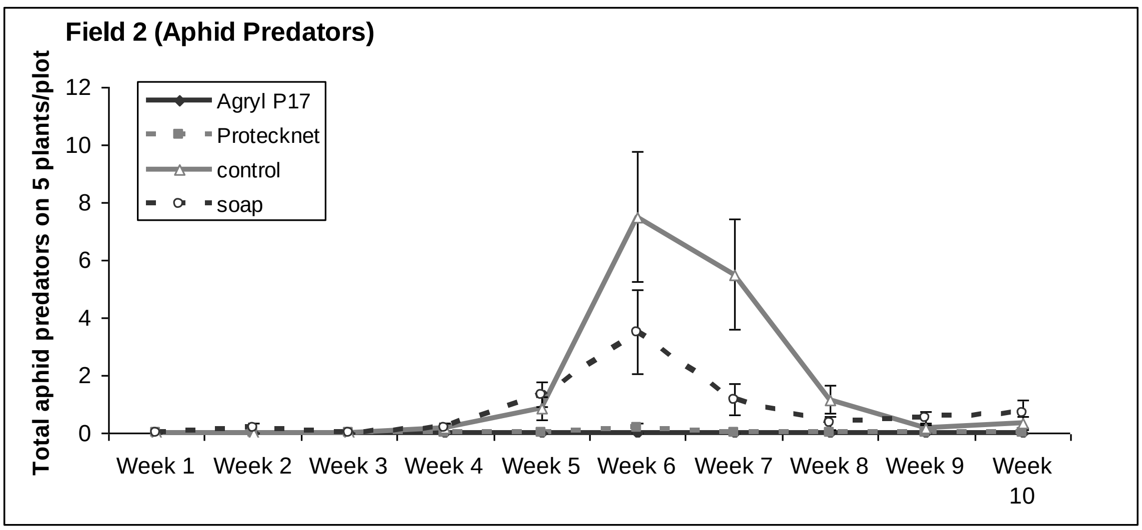


Figure 5. Effect of two types of row cover and industry standard treatment of Soap on yield in cole crops (broccoli). Each bar represents the mean ± s.e. of six replicates/ treatment (total N=24). Bars with the same letters (Field 1) are not significantly different from each other.

Treatment Effects (Field 2) - There was a significant effect of row cover treatment, time and the interaction of Treatment X Time on aphid levels in Field 2 (Fig. 6a; Treatment: $F (3,20) = 14.98$, $P < 0.0001$;Time: $F (9,12) = 23.81$, $P < 0.0001$;Treatment X Time: $F (27,36) = 3.81$, $P = 0.0001$). Profile analysis for each date indicates that both Protecktnet and Agryl P17 provided season long protection against aphids in Field 2, with aphid levels remaining at zero in all Protecktnet plots. Aphid levels went down on their own in the Control and Soap plots. Soap initially did not provide effective aphid control (Fig. 6a). Examination of aphid predators in Field 2 indicates that there were significant negative effects of row covers on aphid predators (Fig. 6b; Treatment: $F (3,20) = 11.56$, $P = 0.0001$;Time: $F (9,12) = 9.39$, $P = 0.0003$; Treatment X Time: $F (27,36) = 2.22$, $P =0.01$). Both types of row covers effectively excluded not just aphids but also aphid natural enemies for the duration of the trial. In contrast in the Control and Soap plots aphid predators slowly built up over the trial, and were significantly higher in the Control plots than either type of row cover plot for each week in August. Natural enemy levels went down on their own in September in both the Control and Soap plots.

Finally, there was a significant effect of row cover on caterpillars in Field 2 (Fig. 6c; Treatment: $F (3,20) = 6.45$, $P = 0.0031$;Time: $F (9,12) = 7.48$, $P = 0.001$; Treatment X Time: $F (27,36) = 3.63$, $P =0.0002$). Both types of row covers effectively excluded caterpillars from plots (on average 0 to 0.17 caterpillars/plot/week for all 10 weeks). In contrast, caterpillar counts ranged from 0 to 10 caterpillars/plot/week over the course of the 10 weeks of the trial in both Control and Soap treated plots. Differences between Control and row cover plots were significant in Weeks 2, 3, 4, 6, and 9. Yield was not impacted by row cover treatments in Field 2 (Fig. 5; Treatment: $F(3,20) = 2.72$, $P = 0.07$), plants grown under Agryl P17 or Protecktnet had slightly deformed outer leaves, due to the row cover sitting on plants, but heads were unaffected (Fig. 7)





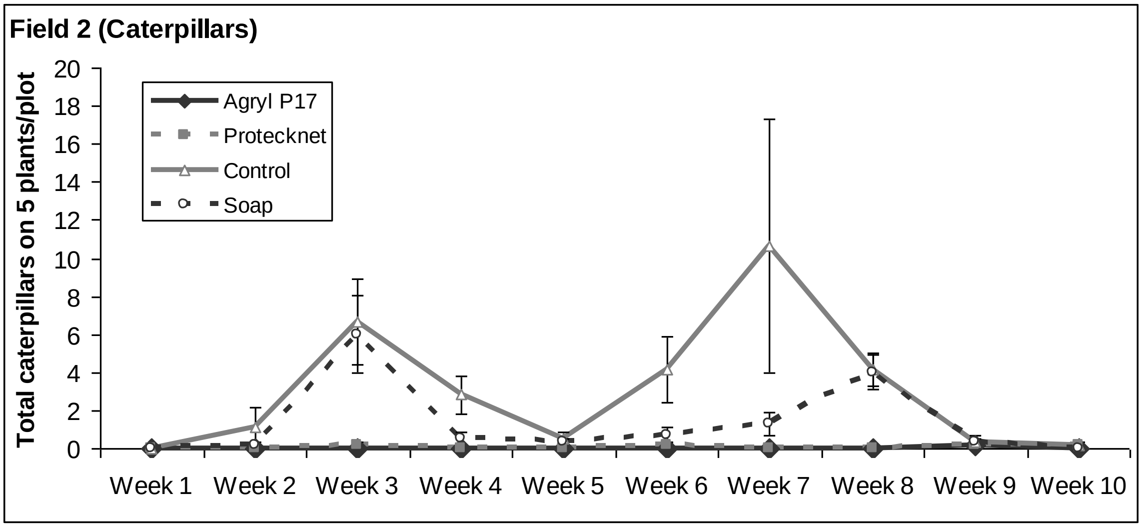
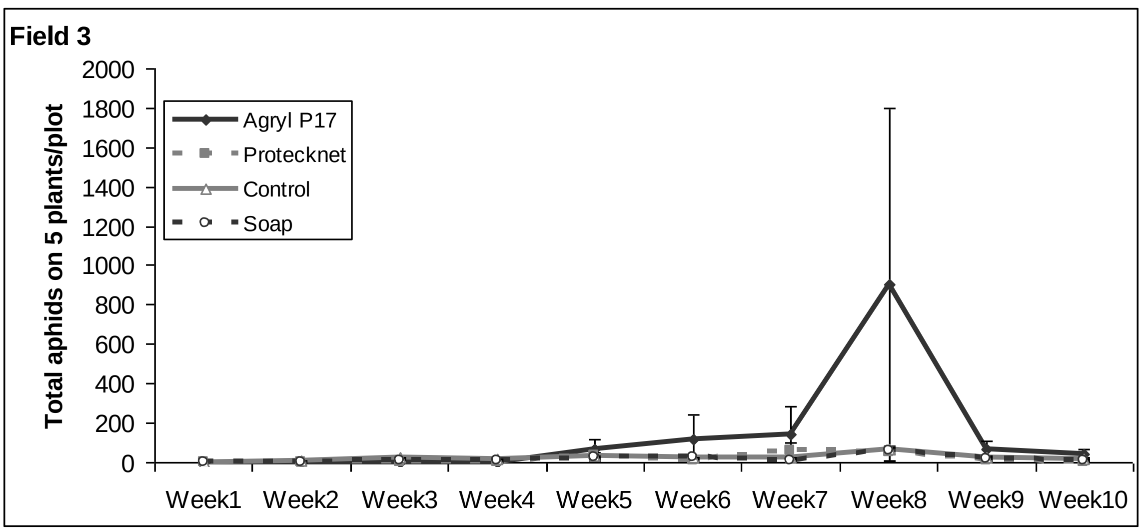


Figure 6. Effect of two types of row cover and industry standard treatment of Soap on a) cabbage aphid infestation, b) aphid predator activity and c) caterpillars in cole crops (cabbage). Each point represents the mean ± s.e. of six replicates/treatment (total N = 24).

Figure 7. Deformed outer leaves under Agryl P17 (left) and Protecknet (right), due to the row cover sitting on plants, but heads were unaffected.

Treatment Effects (Field 3) - There was a significant Treatment X Time interaction on aphid levels in Field 3 (Fig. 8a; Treatment: $F (3,20) = 0.84$, $P = 0.49$; Time: $F (9,12) = 8.45$, $P = 0.0006$; Treatment X Time: $F (27,36) = 2.45$, $P = 0.007$). Profile analysis for each date indicates that after the first week, aphid levels remained near zero in both row cover plots, but gradually increased in the Control and Soap plots in Weeks 2 to 4. However, by Week 5 and for the rest of the trial aphid levels began to increase in both Protecktnet and Agryl P17 plots resulting in no difference among the four treatments for the remainder of the study. Similar to the observations in Field 1, one of the row cover plots (Agryl P17 treatment) had very high aphid levels. This was again because the row cover in the plot had a hole, in the remaining Agryl P17 plots aphids were excluded as the row cover remained intact and without holes.

In Field 3, there was no difference among the four treatments in the number of aphid predators on plants (Treatment: F (3,20) = 1.19, P = 0.34; Time: F (9,12) = 0.64, P = 0.75; Treatment X Time: F (27,36) = 0.24, P = 0.99), with predator counts low overall. When predators were observed it was mainly in Control and Soap plots. Finally, we found a significant row cover effect on caterpillars in Field 3 (Fig. 8b; Treatment: F (3,20) = 18.61, P < 0.0001; Time: F (9,12) = 20.80, P < 0.0001; Treatment X Time: F (27,36) = 2.57, P = 0.004). By Week 2, caterpillar counts were significantly higher in Control and Soap plots than in either row cover plots. This pattern continued until Week 6, when Entrust was sprayed on all plots, by the grower to prevent economic losses. Although caterpillar counts were reduced by the spray, the impact of the spray was short term and caterpillar numbers steadily increased in Control and Soap plots during Weeks 7 to 9. In contrast, in the row cover plots caterpillar counts remained near zero until Week 10. As was observed in Field 2, yield was not impacted by row cover treatments in Field 3 (Fig. 5; Treatment: F (3,20) = 2.68, P = 0.07), and there was again a slightly deformity in outer leaves but no deformity in heads of plants grown under row cover (Fig. 7).



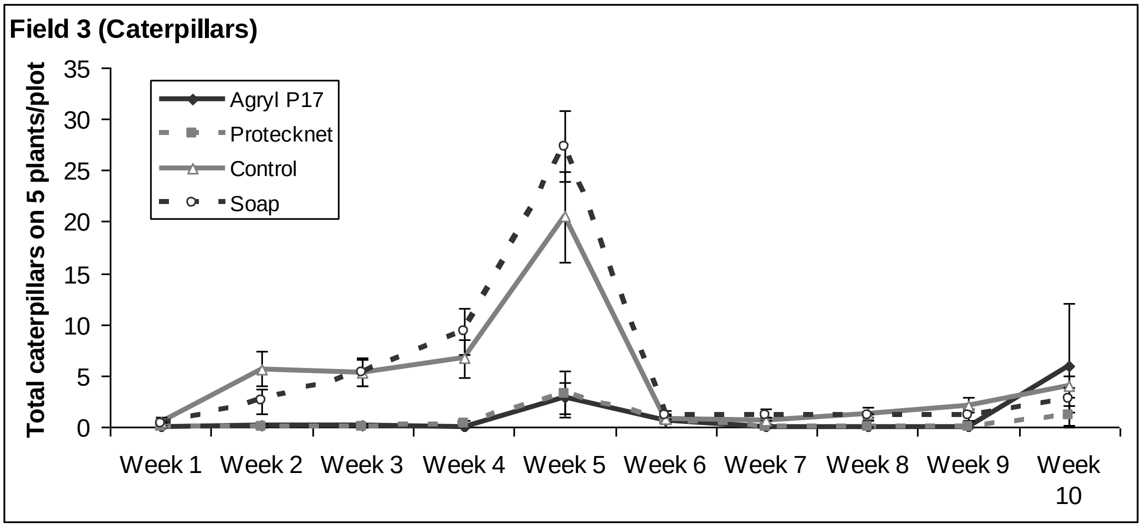


Figure 8. Effect of two types of row cover and industry standard treatment of Soap on a) cabbage aphid infestation, and b) caterpillars in cole crops (cabbage). Each point represents the mean ± s.e. of six replicates/treatment (total N = 24).

Chemical Control (Spray Trial in Peas)

Effect of field – There were significant differences between the three fields (Field: F (2,69) = 1.57, P < 0.0001; Time: F (5,65) = 29.88, P < 0.0001; Field X Time: F (10, 130) = 11.51, P < 0.0001). Initially, all three fields had similar aphid levels, however within two weeks levels were 10X higher in Field 3 than Field 1. Because of this significant field effect, the impact of insecticides on aphids was analyzed separately for each field.

Treatment effects (Field 1): There was no significant effect of insecticides on aphid levels in Field 1 (Fig. 9; Treatment: F (3,20) = 0.99, P = 0.41; Treatment X Time: F (15, 45) = 1.16, P =0.34). Aphid levels in all treatments peaked in Weeks 2 and 3, but then declined in all treatments including the Control by Week 5, leading to a significant time effect (Time: F (5,16) = 16.86, P < 0.0001).

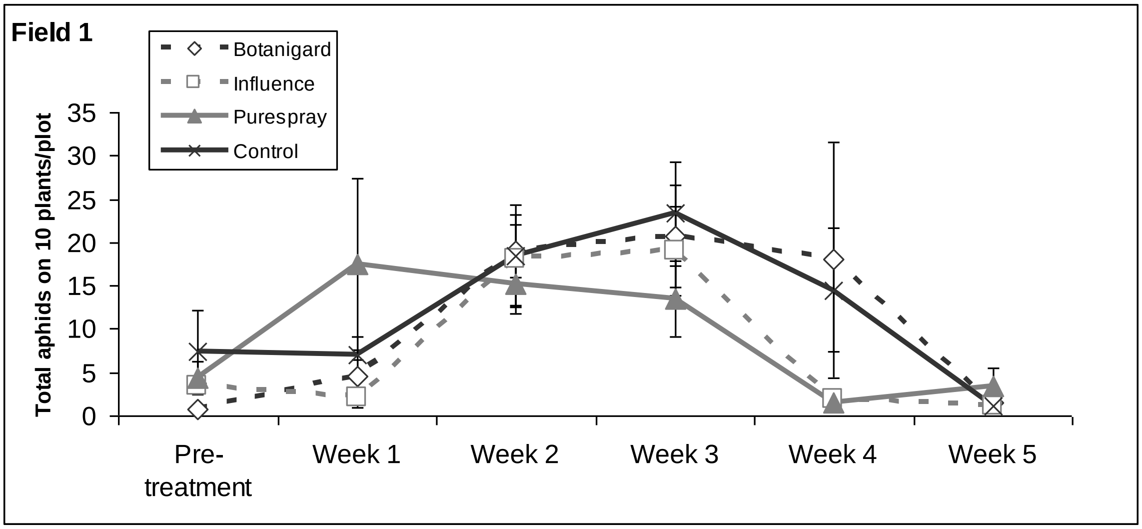


Figure 9. Effect of three insecticides on pea aphid infestation in Field 1. Each point represents the mean ± s.e. of six replicates/treatment (total N = 24).

Treatment effects (Field 2): There was no significant effect of insecticides on aphid levels in Field 2 (Fig. 10; Treatment: F (3,20) = 2.00, P = 0.15; Field X Time: F (15, 45) = 1.23, P =0.29). Aphid levels in all treatments increased over time leading to a significant time effect (Time: F (5,16) = 11.44, P < 0.0001).

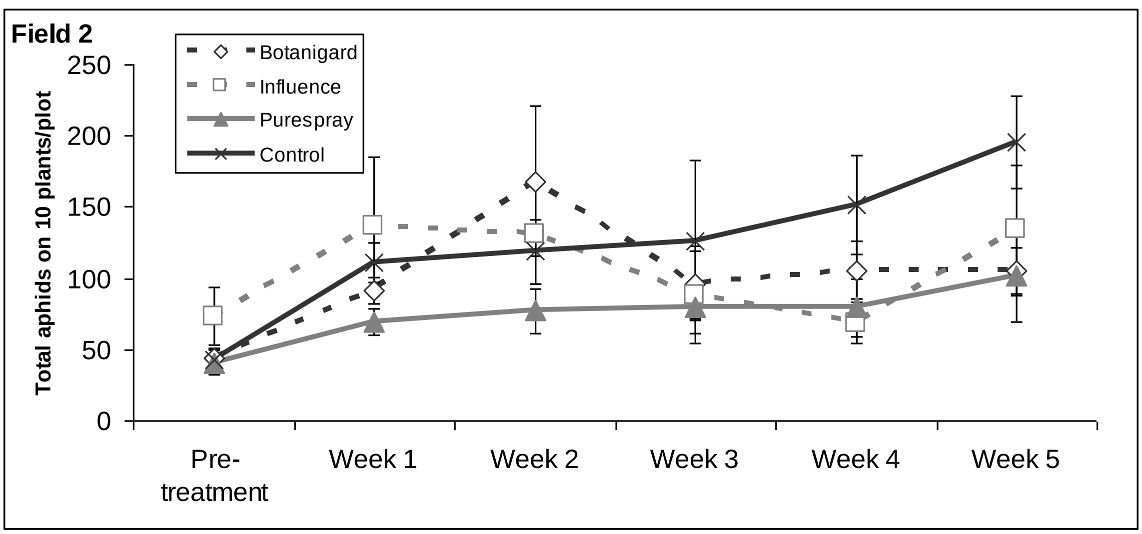


Figure 10. Effect of three insecticides on pea aphid infestation in Field 2. Each point represents the mean ± s.e. of six replicates/treatment (total N = 24).

Treatment effects (Field 3): Unlike Fields 1 and 2, there was a significant effect of insecticide treatment on aphid levels over the five weeks of the study in Field 3 (Fig. 11; Treatment: F(3,20) = 5.27, P = 0.008; Time: F(5,16) = 76.45, P < 0.0001; Treatment X Time: F (15, 45) = 2.81, P = 0.004). Subsequent profile analysis indicates that the Purespray treatment caused a significant reduction in aphids after the first, second, and third sprays compared to the water-treated Control. Following the fourth spray aphid levels were not significantly different among any treatments. However after the last spray the Purespray treatment had fewer aphids than any of the other treatments.

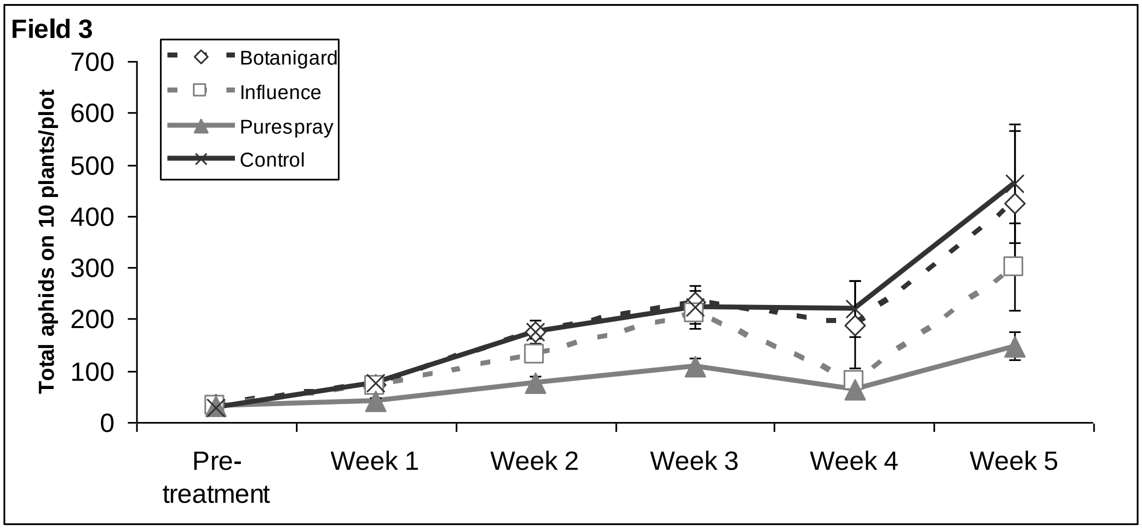


Figure 11. Effect of three insecticides on pea aphid infestation in Field 3. Each point represents the mean ± s.e. of six replicates/treatment (total N = 24).

Chemical Control (Spray Trial in Cole Crops)

Effect of field – There were significant differences between the three fields (Field: F (2,87) = 51.26, P < 0.0001; Time: F (5,83) = 26.53, P < 0.0001; Field X Time: F (10, 166) = 10.37, P < 0.0001). Even prior to treatment aphid levels were dramatically higher in Field 3 than Fields 1 or 2, and remained so for the duration of the trial. Because of this significant field effect, the impact of insecticides on aphids was analyzed separately for each field.

Treatment effects (Field 1): There were significant effects of insecticide treatment on aphid levels in Field 1 (Fig. 12; Treatment: F (4,25) = 8.15, P = 0.0002; Time: F (6,20) = 18.43, P < 0.0001; Treatment X Time: F (24,70) = 2.04, P = 0.01). Purespray and Influence treatment resulted in significantly lower aphid counts in plots compared to the water Control from Week 3 to the end of the trial on Week 6 (Purespray) or to Week 5 (Influence). However for both treatments aphid levels increased over the course of the trial and reached levels that would still have been unacceptable to the grower or consumers (e.g. 236 to 700 aphids/3 plants/plot). Also neither Purespray nor Influence outperformed Soap in this field. Botanigard treatments were not significantly different from the Control and had significantly more aphids than the standard treatment of Soap.

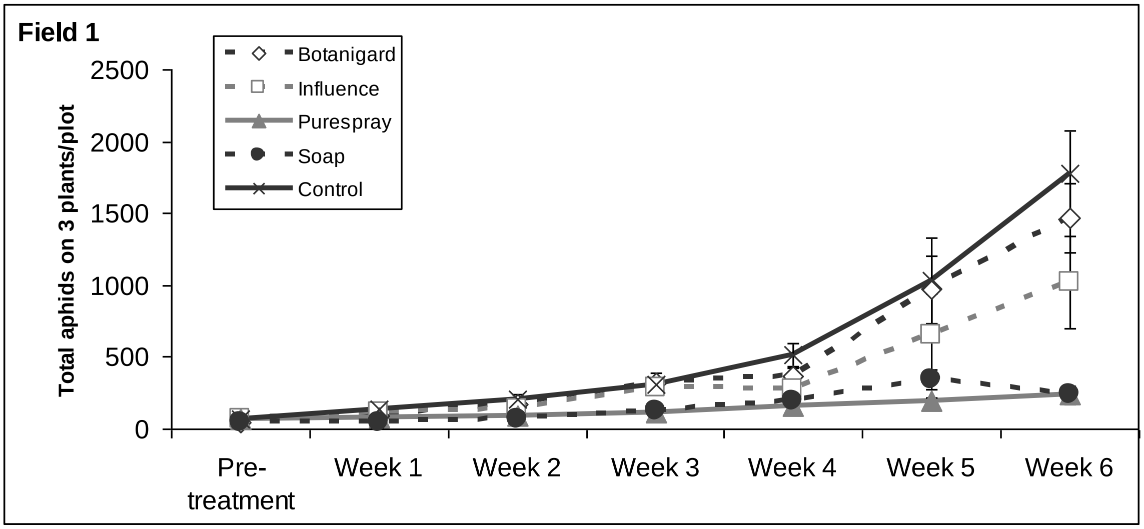


Figure 12. Effect of three insecticides and the industry standard Soap on cabbage aphid infestation in broccoli (Field 1). Each point represents the mean ± s.e. of six replicates/treatment (total N = 24).

Treatment effects (Field 2): There were significant effects of insecticides on aphid levels in Field 2 (Fig. 13a; Treatment: $F (4,25) = 7.10$, $P = 0.0006$; Time: $F (6,20) = 45.78$, $P < 0.0001$; Treatment X Time: $F (24,70) = 2.00$, $P = 0.01$). Aphid levels remained fairly low and similar in all treatments both prior to treatment and for the first week after weekly sprays began. However, by Week 2 there were significantly fewer aphids in the Soap and Purespray plots than the water Control. Aphid counts were significantly lower in Purespray plots compared to the Control in Weeks 2, 3, 4, and 6. The garlic-based product Influence caused a significant reduction in aphid counts compared to the Control in Weeks 2 and 3. However, despite both of these products - Purespray and Influence causing significant reductions in aphid infestation levels compared to the Control, there were still cabbage aphids present on plants following treatment with both products (Fig. 13). The highest weekly average count in Purespray plots was 98 aphids/3 plants/plot and 126 aphids/3 plants/plot in Influence plots. Finally, as was the case with Field 1 neither Purespray nor Influence performed better than Soap during this trial. Botanigard did not cause a significant reduction in aphids compared to the Control. Interestingly, aphid levels declined on their own across all treatments in this field, including the Control. We suspected that this may have been due to the action of aphid predators (natural occurring syrphids, ladybugs, and Aphidoletes). Although aphid predator counts did increase over the course of the trial - peaking in Week 4 (Fig. 13b; Time: $F (6,20) = 6.52$, $P = 0.0006$), there were no significant Treatment or Treatment X Time effects on predator levels (Treatment: $F (4,25) = 2.00$, $P = 0.12$; Treatment X Time: $F (24,70) = 1.61$, $P =0.06$). Nevertheless, the Week 4 peak in predators followed by the decline in cabbage aphids observed in Week 5 onwards, does provide some evidence that natural occurring predators can play a role in regulating aphid populations, but the control may not occur early enough to avoid economic damage.

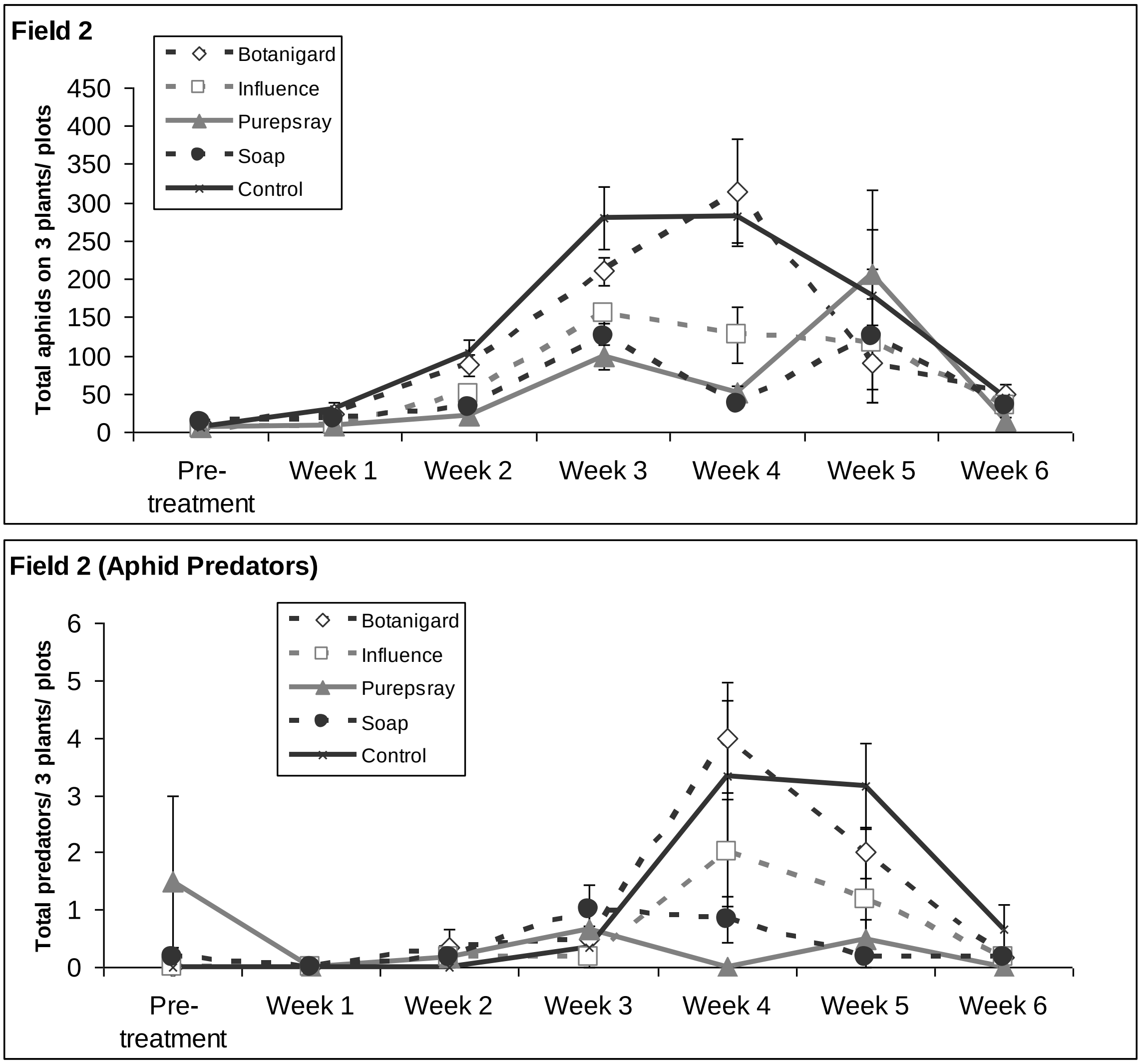


Figure 13. Effect of three insecticides and the industry standard Soap on a) cabbage aphids and b) aphid predators in cabbage (Field 2). Each point represents the mean ± s.e. of six replicates/treatment (total N = 24).

Treatment effects (Field 3): There was no significant effects of insecticides on aphid levels in Field 3 (Fig. 14; Treatment: F (4,25) = 0.67, P = 0.62; Treatment X Time: F (20,70) = 0.86, P =0.63). Aphid levels did increase steadily over the duration of the trial in all plots, leading to a significant effect of time (Time: F (5,21) = 15.87, P < 0.0001). Aphid levels were the highest in Field 3, even prior to the start of the trial - with average pre-spray counts ranging from 127 to 500 aphids/3 plants/plots.

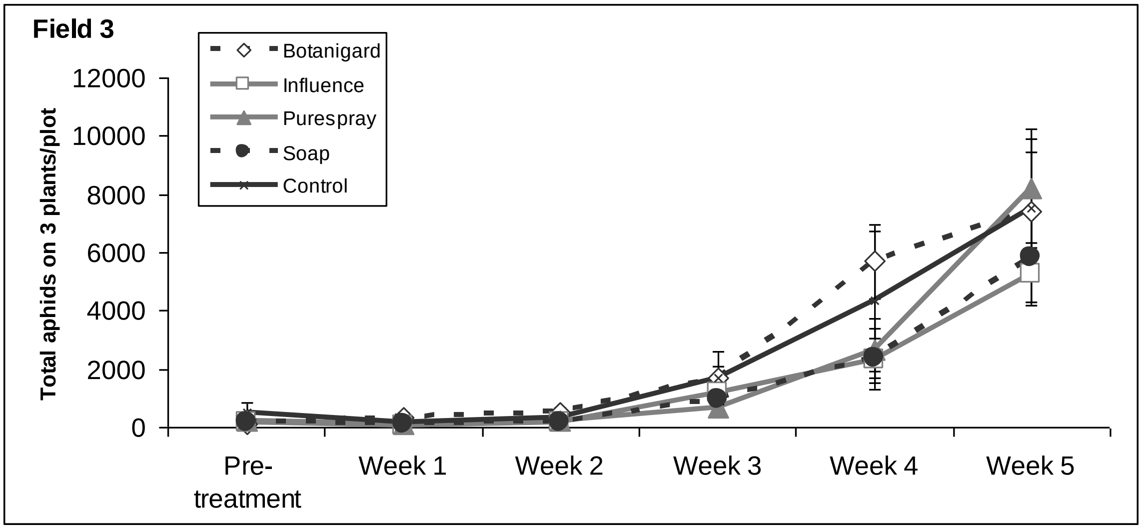


Figure 13. Effect of three insecticides and the industry standard Soap on a) cabbage aphids and b) aphid predators in cabbage (Field 2). Each point represents the mean ± s.e. of six replicates/treatment (total N = 24).

DISCUSSION

The objective of this study was to evaluate several different tools for control of aphids in two vegetable crops - peas and cole crops (cabbage and broccoli). These crops were the focus of the study because they are locally important to organic growers and because aphids can cause significant losses for both crops. We examined tools that are currently available but not widely used by growers - biological control using *Aphidoletes aphidomyza*, conservation of naturally occurring enemies, and row covers. We also examined tools that are not currently available to growers but have the potential to be via product registration or label expansion - insecticides using garlic extract (Influence), mineral oil (Purespray), or entomapathogenic fungi (Botanigard). All of our trials were conducted in growers fields and were often repeated in different fields, thus we were able to determine the various conditions under which a particular tool would be effective.

First we examined whether the biological control agent *A. aphidomyza* could be used in for pea aphid control in field peas. Further we wanted to determine whether providing floral resources (pollen and nectar) via insectary plants could further enhance the activity of Aphidoletes and other naturally occurring biological control agents. We did not observe any impact of Aphidoletes releases on pea aphids (Fig. 3a), nor did we find any Aphidoletes larvae (released or native) on peas in the weeks following release. Further, the insectary plants that were provided did not support increased activity of Aphidoletes or other naturally occurring enemies (e.g. ladybugs, syrphids, parasitoid wasps Fig. 3b and c). Although Aphidoletes are used successfully for aphid control in vegetable greenhouses, efficacy even in the greenhouse environment is not always consistent

(Schelt and Mulder 2000). Some reasons for variable efficacy include poor mating prior to release into the crop and predation of eggs by other natural enemies (intraguild predation) (Schelt and Mulder 2000). Both of these factors may have impacted performance in our study. Also the release rate used in our field trials was based on rates used in greenhouses. However, higher release rates may be needed in the field compensate for increased risks of predation and losses due to more variable environmental conditions - e.g. rain and less humidity during the day. Meadow *et al*. (1985) were successful in controlling aphids with Aphidoletes with a release rate of two to three larvae/plant. However, higher release rates would increase costs (Table 5) which may not be warranted given the overall low value of field peas. In addition to higher release rates another change in release protocol could be to release Aphidoletes with a small amount of pests (e.g. an aphid species that does not attack peas). Such an approach is used to help parasitoid wasps establish in greenhouse crops, and would provide released Aphidoletes with a food source nearby so that populations can build more quickly. Infesting insectary planters with the alternate aphid species and concentrating Aphidoletes release closer to insectary planters could improve the establishment and efficacy of Aphidoletes for aphid control in field peas.

Other natural enemies could also be considered for release or conservation. In earlier studies augmentative releases of adult ladybugs (*Hippodamia convergens*) were not successful (E.S. Cropconsult Ltd. unpublished data). Syrphids are frequently observed on pea plants once aphid levels reach high numbers (E.S. Cropconsult Ltd. unpublished data). The build up of syrphids however could be more effective if it occurred earlier. Nieto *et al.* (2006) showed that lettuce aphid populations were kept low by syrphids, only in years when syrphids were able to colonize fields early in the season. In other systems providing flowering plants either within the field or along field edges has been shown to increase the abundance and impact of syrphids (Smith and Chaney 2007, Schmidt *et al.* 2004, Bowie *et al.* 1999). We may not have seen an impact of our insectary plants on syrphids and the other aphid predators in this study because we did not have a high enough density of insectary plants set out in the field. In California, lettuce growers interplant alyssum, for attracting parasitoid wasps and other beneficials, along entire rows of lettuce (Smith and Chaney 2007). White *et al.* (1995) surrounded cabbage plots with borders of *Phacelia tanacetifolia* and found that syrphid numbers increased compared to Control treatments. Thus an alternate approach for providing the floral resources is to plant insectary plants as continuous strips within the field or along field borders rather than in pots and in patches. However, planting strips or borders of specific flowering plants directly into the field may not ensure that plants are flowering early enough to attract syrphids and other predators to the field. By holding our insectary planters in the greenhouse under artificial light regimes prior to setting out in the field we ensured that flowers, and thus pollen and nectar, were available to natural enemies when planters were placed in the field.

The second approach to aphid control that we examined was the use of row covers. Row covers act as physical exclusion keeping aphids off of plants. We only examined row covers for control of cabbage aphids in cole crops because field peas are a low value short term crop and the expense of row covers would not be justified (Table 5). Also cole crops are more amenable to row covers because they are planted in beds - so individual beds could be covered or multiple beds at one time. We found that both types of row covers were equally effective at keeping aphids off of the crop and overall provided more consistent and longer duration of aphid control than Soap, which provided inconsistent control. We also saw that in some cases the row covers could be effective at excluding caterpillars from the crop as well. However, row covers also effectively exclude aphid predators, thus aphid populations can explode if a few individuals get under the cover as was the case in a row cover plot in each of Field 1 and 3. Tears and poorly secured row covers can result in aphids and other pests being able to get to plants under the row cover. In one of our fields, transplanted mid-May, we found significant increases in yield in plots covered with Agryl P17, most likely due to the increased soil and air temperature caused by this row cover. However this effect was not observed in the remaining two fields (planted late June and mid July) or in other studies using Agryl P17 (e.g. Rekika et al. 2009). It might be that early crop would benefit more from higher soil and air temperature. While this can have a positive impact on plant growth, it can also increase disease pressure such as downy mildew **(***Peronospora parasitica)* and black rot (*Xanthomonas campestris pv. Campestris*) and close monitoring of the crop is recommended in order to assess disease pressure.

Although effective a major limitation with row covers is the cost associated with them (Table 5). Protecktnet is almost 20X more costly than Soap (not including the labour associated with each). Agryl P17 is 5X more costly than Soap (again not including labour). However, many growers report that Agryl P17 is quite fragile and often times does not last the entire field season. In contrast Protecktnet is very durable, tears can be repaired with duct tape, the cover can be reused for at least 7 years if not longer. In the UK where Protecktnet has been used since the late 1990's some suppliers sell previously used Protecknet at a lower cost. Both Agryl P17 and Protecktnet can provide protection against other insect pests in other crops - so can be re-used extensively.

Table 5. Cost comparisons of various chemical, physical and biological control tools examined for pea and cabbage aphid control.

Treatments	**Cost/ha**	Peas: Cost/ season (60 day crop, 1 X/week)	Cole crops: Cost/ season (60 day crop, 1 X/week)	**External cost**
Chemical control				
Soap[1]	$111/application		$888	Sprayer + Labour
Purespray green[2]	$159/application		$1272	Sprayer + Labour
Botanigard[3]	$300/application		$2400	Sprayer + Labour
Influence[4]	$110/application		$880	Sprayer + Labour
Physical control (tested in cole				

crops only)				
Protecknet (with hoops)[5]	$19 250 (good for 7 years)	N/A	$ 19,250 ($2750 if re-used for the minimum of 7	Machinery + Labour (Installation, removing covers for weeding)
Agryl P17[6]	$ 4127 (good for 1 year)	N/A	$4127	Machinery + Labour (Installation, removing covers for weeding)
Biological control (tested in peas only)				
Aphidoletes[7]	$667		N/A	Labour (3 releases)
Insectary Planters[8]	$450 ($30/planter - but plants can also be planted in field)		N/A	Labour (planting, setting in the field, possibly maintenance)

1. Price based on local supplier
2. Product not currently sold in Canada. Price based on retail prices in US (converted to Canadian dollars)
3. Product is available in Canada, but for greenhouse use only. Price based on retail prices in US (converted to Canadian dollars)
4. Product not currently sold in Canada. Manufacturers estimate
5. Price based on sole Canadian supplier
6. Price based on local supplier
7. Price based on local supplier
8. Price estimate based on total costs of plants/planter

The third and final approach to aphid control examined in this study was chemical control using three different types of insecticides suitable for organic production. An advantage of insecticides is that they remain cost-effective when compared to the other organic solutions available (Table 5). When starting with high aphid populations we did not see any efficacy of the products tested. Also in Field 1 peas (Fig. 9), the overall aphid population was very low overall and declined on its own, so we again saw no efficacy of the products tested in this field either. In both peas and cole crops we observed efficacy of products when the pre-treatment aphid counts were quite low (i.e. < 30 aphids/plot in peas and < 10 aphids/plot in cole crops). Under these starting conditions the two products that were consistently effective were Purespray and Influence. Weekly Purespray sprays provided significant levels of aphid control compared to the water Control in three of the six fields (i.e. Field 2 and 3 cole crops and Field 3 peas). However, even in these fields we still saw aphids in Purespray plots, and in the cole crop fields the performance of Purespray was similar to weekly Soap sprays, which is a cheaper option for growers (Table 5). Influence provided significant levels of aphid control compared to the water Control in two of the three cole crop fields, but not in peas. As with Purespray we still saw aphids in Influence-treated plots and the product did not outperform Soap, which again is a slightly cheaper product (Table 5), although it is not currently used for field peas by our collaborating grower.

Interestingly, we observed in one of the cabbage fields that Purespray treated plots had more crucifer flea beetles (and more associated damage) than any other plots (Fig. 14). That field had a large crucifer flea beetle population, unlike the other two fields. However, crop damage due to crucifer flea beetle could have been avoided in the Purespray plots in this field with the addition of Entrust to the weekly Purespray treatment.

Figure 14. In one of our cabbage fields Purespray treated cabbage plants (left) had more crucifer flea beetles than any other plots (right).

Factors which could improve the efficacy of Purespray and Influence against aphids are more frequent sprays - for example from weekly to every four days and better spray coverage. In our study we used hand-pumped backpack sprayers to apply products, efficacy with mechanized sprayers may be different. Chueca *et al*. (2009) found that coverage of orange trees and pest control with horticultural oil improved when an air blast sprayer was used for application rather than a rotary atomizer. Lo *et al*. (1999) found that mineral oil was effective at controlling green peach aphid at the small scale but not in larger plots. These authors also suspected that spray coverage was a factor in the variable efficacy of mineral oils as the scale of the treatment area increased. The efficacy of Purespray and Influence may also be improved if they are used in combination with either each other or other organic insecticides (Mohan *et al*. 2007) and other control tactics. For example, studies are currently underway to determine how best to combine reduced-risk and organic insecticide with conservation biological control in field-grown crops like soybeans, apples, and blueberries (Ohnesorg *et al*. 2009). Of course combining Purespray or Influence with other control tools or increasing the frequency of sprays would further increase costs.

We found no efficacy of the *Beauveria bassiana* formulation Botanigard against cabbage aphids or pea aphids, which was surprising given that Botanigard has demonstrated efficacy against aphids, as well as thrips and whitefly (Greer 2000). However, given that aphid populations were quite high in several of our fields the weekly spray interval may not have been enough. Intervals of two to five days are recommended on the Botanigard label for heavy pest infestations and may have provided better efficacy in this study. Furthermore, environmental conditions - especially humidity - may not have been high enough or consistent enough for optimal performance of *B. bassiana* (Greer 2000). Finally, we observed that Botanigard droplets were beading (rather than sticking) on the foliage of both cole crops and peas (Fig. 15) and that there was more run off as a result. Perhaps an adjuvant (spreader or sticker) is needed in order to increase the effectiveness of this product on waxy type plants such as cabbages, broccolis and peas. Although the results of this study did not demonstrate efficacy, further testing with Botanigard and other *B. bassiana* formulations is still recommended as these products have efficacy against multiple pests, maybe more effective under different environmental conditions (e.g. at the start of the field season when humidity is higher and pest pressure is lower), and could have synergistic effects when used in combination with other insecticides (e.g. mineral oils or garlic) (Mohan et al. 2007).

Figure 15. Botanigard treatment forming droplets on broccoli (left) and pea (right) leaves.

Overall, this study demonstrated that physical control using row covers is a viable control option for cabbage aphid control in cole crops. Other pests like caterpillars may also be controlled. Although both row cover options tested are currently available in Canada a major limitation for many growers will be costs (Table 5). An advantage of Protecktnet is that it can be re-used for many years. We did not find any impact of augmentative releases of *Aphidoletes aphidomyza*, either on their own or in combination with insectary plants, on pea aphids. However, our study was very preliminary and many variables can be altered to improve performance - e.g. release rate, release timing, combinations of released and conserved predators. However, all biological control tactics will have costs associated with them, and these costs may not be justified in a relatively low value crop like (fresh market or processing) peas. Finally, of the insecticide options examined, Purespray and Influence showed the most promise and further studies should be conducted on product rates, application frequency and application method (to ensure optimal coverage). Both products are potential tools for the pest management tool box for organic field vegetable production.

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Appendix I- Aphidoletes and spray trials in 3 organic pea fields; field map showing plot size and treatments layout.

Field 1 (G4)- Peas						N
		1m				
Influence	buffer 0.5m	Purespray green	2m			
0.5m buffer						
Purespray green		Botanigard				
Water control		Influence				
Botanigard		Influence				
Botanigard		Purespray green				
Purespray green		Purespray green	Control	Aphidoletes and	Aphidoletes	48 m
Influence		Botanigard		Insectary plants		
Botanigard		Water control	1008m2			
Water Control		Purespray green	0.25 acre			
Influence		Water control				
Botanigard		Water control				
water control		Influence				
			21 m	21 m	21 m	

Field 2 (G6)-Peas								N	
Botanigard	Purespray green	Botanigard	Influence	Purespray green	Water control	Botanigard	1 row	botanigard	
			0.5 m buffer				buffer		
Influence	Influence	Water control	Water control	Purespray green	Influence	Botanigard		Influence	
			0.5m buffer						
Water control	Botanigard	Purespray green	Influence	Water control	Purespray green	Water control		Purespray green	2m
								2 rows	
			Control						
			2800 m2						70 m
			0.7 acre						
			Aphidoletes and Insectary plants						70 m
			Aphidoletes						70 m
			40 m						

Field 3 (T9)-Peas

				2 rows		
Purespray green		Botanigard	I row	Water control	2m	N
Influence	I row	Purespray green	Buffer	Botanigard		
Botanigard		Purespray green		Water control		
Water control		Influence		Influence		
Influence		Purespray green		Influence		
Influence		Botanigard		Botanigard		
Botanigard		Water control		Purespray green		
Water control		Water control		Purespray green		
		Aphidoletes				55 m
		3740 m2				
		0.9 acre				
		Aphidoletes				55 m
		and				
		Insectary plants				
		Control				55 m
		68 m				

Appendix II- Row covers trial; treatments layout in each of the 3 fields (field 1, broccoli; field 2 and field 3 cabbages)

Field 1			**Field 2**			**Field 3**	
Treatment	**Rep**		**Treatment**	**Rep**		**Treatment**	**Rep**
Protecknet	1		soap	1		Protecknet	1
soap	1		control	1		soap	1
soap	2		Protecknet	1		Agryl P17	1
control	1		soap	2		Protecknet	2
Agryl P17	1		Agryl P17	1		soap	2
Protecknet	2		Protecknet	2		Protecknet	3
soap	3		control	2		Agryl P17	2
Protecknet	3		control	3		Control	1
soap	4		Protecknet	3		control	2
control	2		Agryl P17	2		Agryl P17	3
Agryl P17	2		soap	3		Protecknet	4
control	3		Agryl P17	3		soap	3
control	4		Protecknet	4		control	3
control	5		control	4		control	4
Agryl P17	3		soap	4		Agryl P17	4
Protecknet	4		Protecknet	5		Protecknet	5
Agryl P17	4		Protecknet	6		soap	4
Protecknet	5		Agryl P17	4		control	5
soap	5		control	5		Protecknet	6
Protecknet	6		soap	5		soap	5
soap	6		soap	6		Agryl P17	5
Agryl P17	5		control	6		soap	6
Agryl P17	6		Agryl P17	5		Agryl P17	6
control	6		Agryl P17	6		control	6
↑South			↑North			↑South	

Appendix III. Spray trial in cole crop; treatments layout in each of the 3 fields (field 1 and 3, broccoli, field 2, cabbages)

Field 1			**Field 2**			**Field 3**	
Treatment	**Rep**		**Treatment**	**Rep**		**Treatment**	**Rep**
Soap	1		Botanigard	1		Botanigard	1
Botanigard	1		Purepspray	1		Water	1
Purespray	1		Soap	1		Soap	1
Water	1		Influence	1		Purespray	1
Purespray	2		Botanigard	2		Botanigard	2
Soap	2		Soap	2		Influence	1
Botanigard	2		Purepspray	2		Purespray	2
Water	2		Influence	2		Water	2
Influence	1		Water	1		Purespray	3
Botanigard	3		Purepsray	3		Soap	2
Purespray	3		Soap	3		Soap	3
Influence	2		Influence	3		Botanigard	3
Soap	3		Water	2		Botanigard	4
Water	3		Purepsray	4		water	3
Soap	4		Water	3		Influence	2
Influence	3		Botanigard	3		Soap	4
Purespray	4		Influence	4		Water	4
Influence	4		Soap	4		Botanigard	5
Soap	5		Water	4		Purespray	4
Influence	5		Purepsray	5		soap	5
Botanigard	4		Influence	5		Influence	3
Purespray	5		Purepsray	6		water	5
Soap	6		Botanigard	4		Influence	4
Water	4		Water	5		Purespray	5
Botanigard	5		Botanigard	5		Influence	5
Water	5		Influence	6		Botanigard	6
Purespray	6		Soap	5		Influence	6
Influence	6		Water	6		Soap	6
Water	6		Botanigard	6		water	6
Botanigard	6		Soap	6		Purespray	6
↑north			↑south			↑south	