# Caterpillar control for organic cole crop production: Alternatives to Entrust

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**EXECUTIVE SUMMARY**

Caterpillars of three moth species - cabbage looper (*Trichoplusia ni*), imported cabbageworm (*Pieris rapae*) and diamondback moth (*Plutella xylostella*) - can cause significant economic losses for cole crops. Globally diamondback moth has been identified as the most important insect pest of cole crops. Locally, growers in the Fraser Valley rely almost exclusively on the OMRI-approved insecticide Entrust for control of diamondback caterpillars. In other areas resistance to Entrust has developed in diamondback populations due to over reliance. The concern is that a similar situation is arising in the Fraser Valley as there are no other tools to rotate with Entrust, that are effective against diamondback. Field trials were conducted to test two possible options for caterpillar control - the mineral oil Spray oil 13E and the garlic-based Influence. These two products were tested along side the industry standards Entrust and Dipel (there is anectodal evidence that local diamondback populations are Dipel-resistant), and a water Control. Trials were conducted in three organic cole crop fields in the summer of 2011. All three fields had natural infestations of all three caterpillar species, however we also infested field plots with diamondback caterpillars. Plots were sprayed twice in a seven day interval and counts were done prior to sprays and then several times after each spray. When the impact on the whole caterpillar community and on individual species was examined there was no effect of Spray oil 13E or Influence compared to the Control. However, when the effect on only minute and small caterpillars was examined - in the small window following the first spray - there was a significant reduction in caterpillars compared to the Control in the Spray oil 13E plots. This result suggests that Spray oil 13E should be examined further as it could help to reduce the reliance on Entrust and thus delay resistance to that product, especially among diamondback moths. However, since the effect of Spray oil 13E was only observed on minute and small caterpillars and overall the product did not cause a reduction in the infestation level of plants other methods for caterpillar control in organic cole crops, that could be explored in the future, are also discussed.

## INTRODUCTION

Three species of caterpillars - cabbage looper (*Trichoplusia ni*), imported cabbageworm (*Pieris rapae*) and diamondback moth (*Plutella xylostella*) are the main Lepidopteran species damaging cole crops in BC. Together, these three pests can damage or kill young plants, cause cosmetic injury, contaminate produce and reduce yield as a results of their feeding damage (Fig. 1). Currently, the management program for caterpillars in cole crops is based on weekly monitor of pest populations. Spray recommendations are based on the proportion of plants infested and the action threshold varies with crop stage (Fig. 2). Additionally, larvae size can influence the timing of spray recommendations. For monitoring purposes we categorize larvae into four size categories: minute (just hatched), small, medium and large (full size larva ready to pupate). Although the physical size for each category is different for the three species (Table 1), for all species spray efficacy is best on the youngest caterpillars; spray recommendations are timed to occur when the majority of larvae are in the minute or small stages.

In conventional production, there are many different spray options for growers to use (Diazinon, Decis, Dibrom, Monitor, Orthene, Pounce, Perm, Sevin, Thionex, etc). In organic production however, options are limited. Previously, Dipel (*Bacillus thuringiensis* subsp. *kurstaki*) was the only control product registered for caterpillar control in organic production, in Canada. However, diamondback moth resistance to Btk has been documented throughout the world (Tabashnik *et al.* 1997) and there is considerable anecdotal evidence that local populations are also resistant to Btk (E.S. Cropconsult Ltd. unpublished data). There is also evidence that some local populations of cabbage looper are also resistant to Btk (Janmaat and Myers 2003).

The relatively recent registration of Entrust (spinosad) has provided organic growers with an additional tool for caterpillar control. In the US (California, Georgia and Hawaii), however, populations of diamondback have developed resistance to spinosad because of repetitive uses (Zhao *et al.* 2006). There are several reasons to be concerned that a similar situation could arise locally. First, Entrust is slowly becoming the main tool growers use for diamondback moth control, as efficacy with Btk is poor. Because there are multiple generations of diamondback moth in southwestern BC, at least two to three Entrust applications are often made in a growing season - especially when there are sequential plantings in the same field (Fig. 2). Second, Entrust is the only option available to organic cole crop growers to control crucifer flea beetle (*Phyllotreta crucifera*), which often overlaps with diamondback populations. Therefore, growers often use the three applications of Entrust per year/crop allowed (as per label). Thus there is reason to be concerned about the potential for Entrust-resistance in local diamondback populations, as seen in the US (Zhao *et al.* 2006). Organic cole crop production needs more options for caterpillar control, especially for diamondback control.

Mineral oil could potentially be a control option for caterpillars in cole crops. Mineral oil has been shown to control other Lepidoptera such as corn earworm (*Helicoverpa zea)* and fall armyworm (*Spodoptera frugiperda)* in field trials conducted on corn (Hazzard *et al.* 2003), and citrus leaf miner (*Phyllocnistis citrella)* in lab experiments (Amiri-Besheli 2008). Several mineral oil formulations are available for organic production in the US including, Purespray Green (Petro Canada) and JMS Stylet Oil (JMS FlowerFarms Inc.). Both products are registered for the control of caterpillars such as leafroller and armyworm on vegetable and fruit crops. There are currently no oil-based insecticides registered for organic production of cole crops in Canada. However, Purespray Green is marketed in Canada under the trade name Spray oil 13 E and is registered for fruit trees and blueberries to control scale and mites, and was effective against aphids, when pre-spray populations were low, on cole crops in a previous trial (Dessureault and Prasad 2010). Garlic-based pesticides should also be considered as a potential control option for caterpillars as garlic extracts have been shown to have repellent and insecticidal effects on a broad range of insects, including the citrus leafminer (Amiri-Besheli 2008). Influence (AEF Global Inc.), a garlic-based product, is now registered in Canada for disease control and is approved for organic production. Since both products have the potential to be used for organic cole crop production for the management of other pest issues it would be ideal if they could also be used for caterpillar control. The objective of this work was to test the efficacy of mineral oil and garlic-based insecticides as additional tools for caterpillar control that can be used in rotation with Entrust.

Figure 1. Feeding damage on cabbage plants (left) and diamondback larva feeding on a cabbage leaf (right).

Table 1. Number of instars varies from one caterpillar species to another and life cycle can greatly vary with the temperature (Capinera 2005)

| **Caterpillar species** | **Number of instars** | **Approximate sizes (mm) for each larval class** | **Time to complete life cycle (days)** |
|---|---|---|---|
| Cabbage looper | 4-7 | Minute: 3<br>Small:10<br>Medium: 20<br>Large:35 | 18-25 |
| Imported cabbageworm | 5 | Minute: 3<br>Small: 8<br>Medium:17<br>Large: 30 | 21-42 |
| Diamondback moth | 4 | Minute: 1<br>Small: 3<br>Medium:7<br>Large:10 | 17-51 |

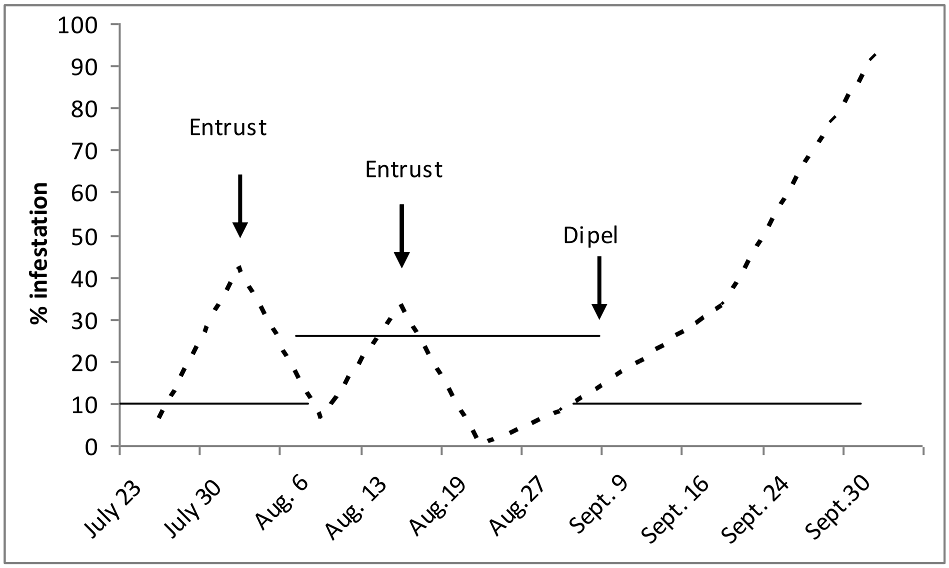


Figure 2. Pest monitoring data collected from a commercial organic cabbage field in Delta, BC, in 2010. Levels of plant infestation with caterpillars and number of sprays and products recommended over the 10 weeks that the field was monitored. The solid lines indicate the action thresholds are 10% at the beginning and end of the field season (young plants and during harvest) and 25% during the middle of season.

## MATERIAL AND METHODS

**Study site:** The trial was conducted in two organic broccoli fields (Field 1 and 2; var. Greenbelt and Bluewind) and in one organic cabbage field (Field 3; var. Lennox), in Delta, BC. Field 1 was planted on May 18, Field 2 on June 09 and Field 3 on June 24. Planting and crop management (pest control, fertilizer and irrigation) were done by the grower. Field plots and a buffer bed on each side of the plot area were left untreated when growers had to apply insecticide to protect their crops.

**Treatment Description and Plot Layout:** In order to evaluate the efficacy of organic insecticides for caterpillar control in cole crops, the trial examined two products 1) Spray Oil 13E and 2) Influence against the industry standards 3) Dipel and 4) Entrust along with 5) a water Control (Table 2). Each of the five treatments was replicated six times, for a total of 30 plots/field. Treatments were randomly assigned to plots resulting in a completely randomized designed. Plots were 1 m long X 1.5 m wide (1 bed) separated by 0.5 m buffer. Plots were laid on a 1 X 36 grid in all three fields (Appendix 1).
Fields were monitored weekly, starting when plants were transplanted, for natural infestation of caterpillars. Natural infestations occurred in all three fields. Treatments began when caterpillar populations were above threshold (25% of plants with caterpillars) in the surrounding field. Plots were sprayed twice in each field with a 7 day interval between sprays, as per the Entrust label (Table 3). Treatments were applied with a backpack sprayer hand-pumped to maintain full pressure. Following the label, plants were sprayed to allow good coverage but to avoid run-off (0.21 L of spray solution/plot).

Table 2. Description of the three treatments evaluated against the water Control for caterpillar control in organic cole crop.

| Trade Name and Manufacturer | Active Ingredient | Rate | Amount of product/plot |
|---|---|---|---|
| Spray Oil 13 E (Petro Canada) | Mineral oil | 1% solution | 2.1 mL |
| Influence (AEF Global Inc.) | Garlic Extract | 5% solution | 10.5 mL |
| Dipel 2X DF (Valent BioSciences Corporation) | *Bacillus thuringiensis* | 275 g/ha | 0.042g |
| Entrust (Dow AgroSciences) | Spinodad | 109 g/ha | 0.017 g |
| Water | | | 0.21 L |

**Pest inoculation:** In addition to the natural occurring caterpillar populations, one plant per plot (that was caterpillar free at the start of the trial) was inoculated with diamondback larvae prior to the first spray. Inoculation rates were: three larvae in Field 1 (one minute and two small following Table 1) and two larvae in Field 2 and 3 (one minute and one small larva). The fields were inoculated in the morning prior to the first spray (Table 4). Field 1 was inoculated with field collected larvae. Field 2 and 3 were inoculated with larvae reared from a diamondback colony which was started in early June from field-collected larvae. The colony was held in a cage (Bugdorm, Bioquip Products) and provisioned with sugar water and broccoli plants for food and oviposition sites (Fig. 3). The colony was maintained at ambient temperature and natural day length.

Figure 3. Diamondback colony was reared for inoculation of plots in Field 2 and 3.

**Assessment**:

Natural Infestations: In order to assess natural infestations, one pre-treatment count and two post-treatment (3days and 7 days) counts were conducted after each spray for a total of five counts (Table 3). The pre-treatment count consisted of recording the number caterpillars seen on all plants from each plot. Further, to minimize caterpillar "migration" into plots any caterpillar eggs found on plants during the pre-count were killed. Only the plants that had caterpillars at the pre-treatment count were assessed for the post treatment counts resulting in a different number of plants assessed for each plot (2 to 8 plants/plot). Counts were converted into larvae/plant to account for the variation in the number of plants/plot. Each count consisted of recording the number of caterpillars of each species and recording their size (minute, small, medium and large - following Table 1). Plants were monitored by carefully looking at all the leaves (upper and lower surfaces) and the head. The number of pupae were also recorded and added to the post-spray caterpillar counts for analysis. Finally, the number of plants with caterpillars was recorded in order the proportion of infested plants/plot (i.e. plants with caterpillars/total plants sampled).

Table 3. Schedule of sprays (two per field) and counts of natural caterpillar infestations to assess spray efficacy

| Sprays | 1st spray | | 2nd spray | | |
|---|---|---|---|---|---|
| Counts | Pre-treatment | Day 3 | Day 7 | Day 11 | Day 14 |
| Field 1 | June 10 | June 14 | June 17 | June 21 | June 24 |
| Field 2 | July 19 | July 22 | July 26 | July 29 | August 02 |
| Field 3 | August 02 | August 05 | August 09 | August 12 | August 16 |

Inoculated plants: For the inoculated plant (1 plant per plot), three post-treatment counts were conducted following each spray for a total of six counts (Table 4). The methods for detecting larvae, size categories and including pupae in the count were done in a similar manner as for the natural infestation, described above.

Table 4. Schedule of caterpillar infestation, sprays (two per field) and counts of artificially infested plants (one plant/plot) to assess spray efficacy.

| Sprays | 1st spray | | | 2nd spray | | | |
|---|---|---|---|---|---|---|---|
| Counts | | Day 1 | Day 3 | Day 7 | Day 8 | Day 11 | Day 14 |
| Field 1 | June 10* | June 12 | June 14 | June 17 | June 19 | June 21 | June 24 |
| Field 2 | July 19* | July 20 | July 22 | July 26 | July 28 | July 29 | August 02 |
| Field 3 | August 02* | August 03 | August 05 | August 09 | August 10 | August 12 | August 16 |

*A single plant in each plot was infested with diamondback caterpillars in the morning prior to the first spray

**Data analyses:** For all results described below (except reduction in minute and small caterpillars), preliminary analyses indicated significant field effects (both as a main treatment effect and in interaction with either treatment or time). Therefore we examined the efficacy of products for each field separately. To assess product efficacy we looked at four parameters: 1) effect on the naturally occurring caterpillar community, 2) effect on plant infestation, 3) effect on individual species (naturally occurring and inoculated) 4) effect on small and minute caterpillars. The effects of insecticide treatments on the naturally occurring caterpillars, individual species and plant infestation were analyzed using repeated measures MANOVA, followed by profile analysis (one-way ANOVA for each date) if the interaction of Treatment X Time was significant. The effect of insecticide treatments on reduction in small and minute caterpillars three days after treatment (DAT) was analyzed using two-way (Treatment X Field) ANOVA. *Post-hoc* means separation was done using Tukey-Kramer HSD test. All data were analyzed using JMP-In Version 5.1 (SAS Institute, Chicago, IL).

## RESULTS

**Effect of treatments on the naturally occurring caterpillar community:** To determine the efficacy of the insecticides tested as potential tools for caterpillar control we first examined their impact on the naturally occurring population of caterpillars of all three species. In all three fields there was a natural decline in the number of individuals (larvae + pupae) over the course of the two weeks, i.e. significant time effects in all fields (Table 5). In all three fields we saw significant treatment effects of Entrust following the first spray (Fig. 4). However, only in Field 3, did we see significant treatment effects following the second spray – this is because only Field 3 had enough pest pressure for the second week of the trial. In Fields 1 and 2, there was an overall decline in caterpillar pests (see Fig. 5 Control Day 14) so determining insecticide effects, for the second week of the trial was not possible. Regardless of whether the response to insecticides only occurred in the first week or both weeks of the trial, in none of the fields did we see a significant difference between the Control treatment and either Spray oil 13E or Influence (Fig. 4).

Table 5. Summary statistical results for analysis of insecticide effects on the whole caterpillar community in plots (number of individual/plant/plot)

| | Repeated measures | Profile Analysis | | | | |
|---|---|---|---|---|---|---|
| Field | | Pre-Count (Day 1) | Day 4 | Day 7 | Day 11 | Day 14 |
| 1 | Treatment: $F(4,24)=5.93$, $p=0.002$ Time: $F(2,23)=10.94$, $p=0.0005$ Treatment X Time: $F(8,46)=3.31$, $p=0.005$ | Treatment: $F(4,24)=0.89$, $p=0.48$ | Treatment: $F(4,24)=8.31$, $p=0.0002$ | Treatment: $F(4,24)=3.92$, $p=0.01$ | N/A | N/A |
| 2 | Treatment: $F(4,25)=218.99$, $p<0.0001$ Time: $F(2,24)=31.53$, $p<0.0001$ Treatment X Time: $F(8,48)=31.53$, $p<0.0001$ | Treatment: $F(4,25)=2.27$, $p=0.09$ | Treatment: $F(4,25)=5.99$, $p=0.002$ | Treatment: $F(4,25)=2.10$, $p=0.11$ | N/A | N/A |
| 3 | Treatment: $F(4,25)=24.94$, $p<0.0001$ Time: $F(4,22)=9.80$, $p=0.0001$ Treatment X Time: $F(16,68)=1.61$, $p=0.09$ | Treatment: $F(4,25)=0.35$, $p=0.84$ | Treatment: $F(4,25)=8.11$, $p=0.0002$ | Treatment: $F(4,25)=11.52$, $p<0.0001$ | Treatment: $F(4,25)=11.40$, $p<0.0001$ | Treatment: $F(4,25)=10.75$, $p<0.0001$ |

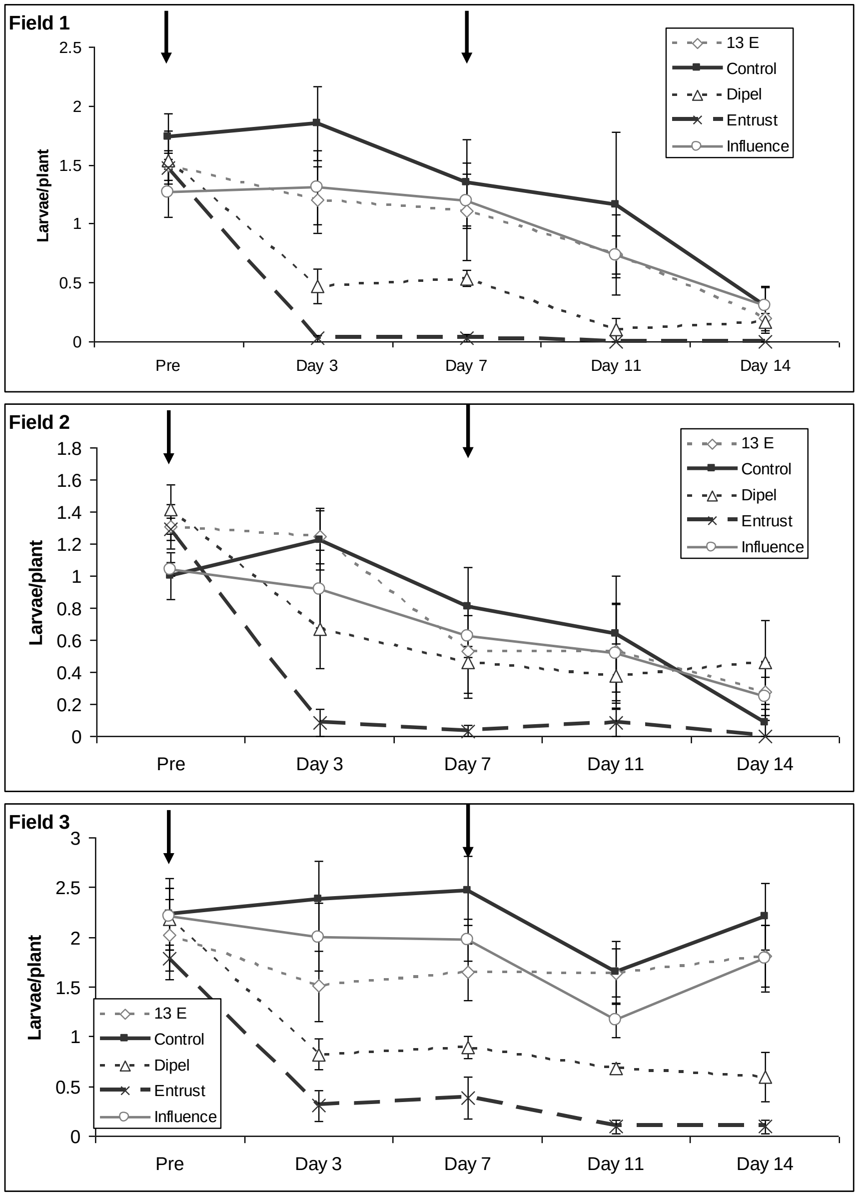


Figure 4. Effect of insecticides on the mean (± s.e.) number of all three caterpillar species/plant/plot following treatment. Sprays are indicated with arrows, counts on each spray day were made prior to the spray. For Field 1 and 2, although results are shown for Day 11 and 14, these data were not included in analyses.

**Effect of treatments on number of infested plants**: Next we examined which treatments were successful in reducing the number of infested plants below the threshold of 0.25 (or one quarter of plants infested with at least one caterpillar). Prior to treatment, plots were on average at or near the threshold (Fig. 5). As with the analysis of the whole caterpillar community, we did not examine the effect of insecticides on infested plants following the second spray in Field 1 and 2. There was a significant effect of the insecticides, primarily Entrust, on infestation levels in all fields (Table 6). Application of Entrust reduced infestations levels below threshold for the first week in Field 1 and 2 and for both weeks in Field 3 (Fig. 5). In contrast, application of Spray oil 13E or Influence did not reduce the infestation levels below threshold or result in a significant difference compared to the Control in any of the fields (Fig. 5). Compared to the Control, Dipel caused a reduction in infestation level on Day 3 in all fields, but not at any subsequent dates in Fields 1 and 2; effects of Dipel on infestation level were also seen on Days 11 and 14 in Field 3 (Fig. 5). While there was an effect on infestation levels from Dipel levels were not brought below the 0.25 threshold (Fig. 5).

Table 6. Summary statistical results for analysis of insecticide effects on plant infestation level/plot (proportion of plants infested with caterpillars/plot)

| | Repeated measures | Profile Analysis | | | | |
|---|---|---|---|---|---|---|
| Field | | Pre-Count (Day 1) | Day 4 | Day 7 | Day 11 | Day 14 |
| 1 | Treatment: $F(4,25)=12.64$, $p<0.0001$<br>Time: $F(2,23)=17.76$,$p<0.0001$<br>Treatment X Time: $F(8,36)=6.32$, $p<0.0001$ | Treatment: $F(4,24)=1.34$, $p=0.28$ | Treatment: $F(4,24)=19.78$ $p<0.0001$ | Treatment: $F(4,24)=7.33$, $p=0.0005$ | N/A | N/A |
| 2 | Treatment: $F(4,25)=4.27$, $p<0.0001$<br>Time: $F(2,24)=5.25$, $p=0.01$<br>Treatment X Time: $F(8,48)=5.25$, $p=0.0009$ | Treatment: $F(4,25)=1.06$, $p=0.40$ | Treatment: $F(4,25)=12.09$, $p<0.0001$ | Treatment: $F(4,25)=4.95$, $p=0.005$ | N/A | N/A |
| 3 | Treatment: $F(4,25)=26.51$, $p<0.0001$<br>Time: $F(4,22)=3.55$, $p =0.02$<br>Treatment X Time: $F(16,68)=3.91$, $p<0.0001$ | Treatment: $F(4,25)=1.26$, $p=0.31$ | Treatment: $F(4,25)=15.26$, $p<0.0001$ | Treatment: $F(4,25)=13.29$, $p<0.0001$ | Treatment: $F(4,25)=15.30$, $p<0.0001$ | Treatment: $F(4,25)=21.20$, $p<0.0001$ |

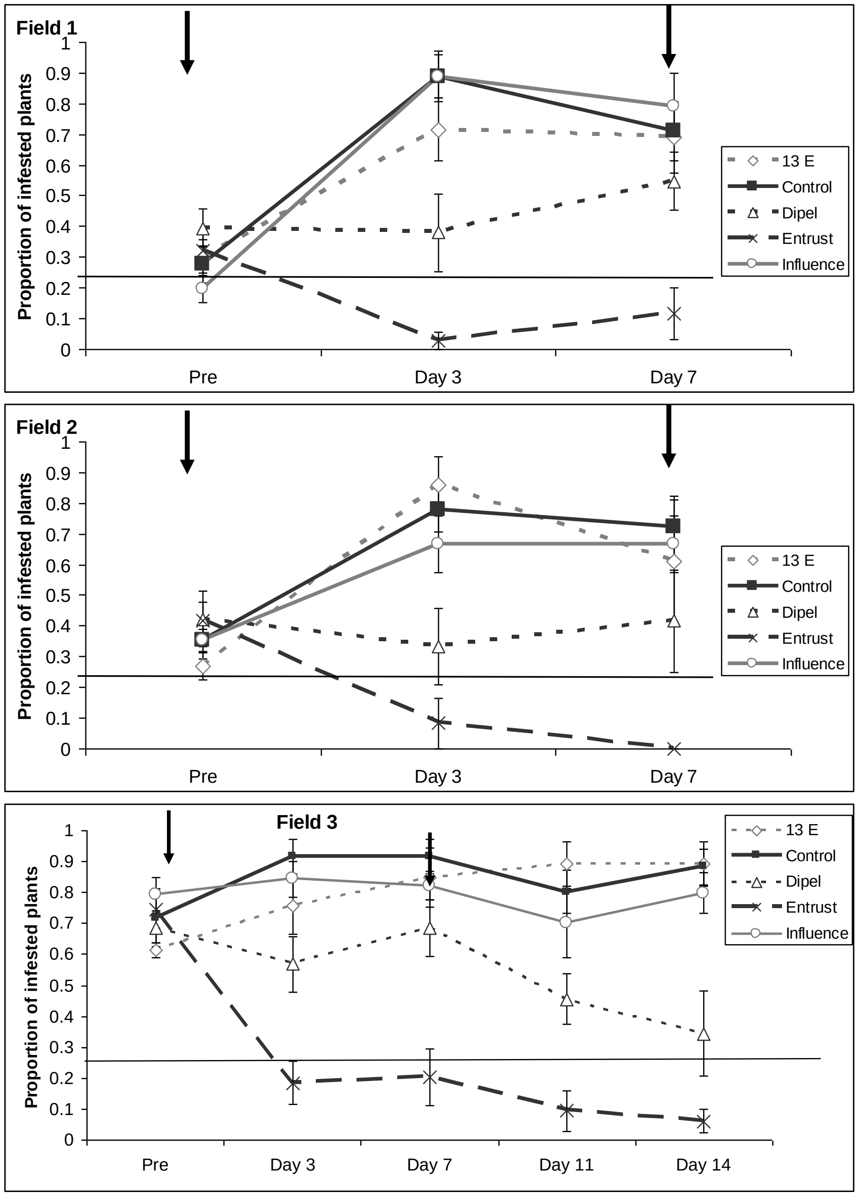


Figure 5. Effect of insecticides on the mean (± s.e.) proportion of caterpillar infested plants/plot following one (Field 1 and 2) or two (Field 3) sprays. Sprays are indicated with arrows, counts on each spray day were made prior to the spray. The horizontal line indicates the action threshold of 0.25 infested plants.

**Effect on individual species:** Because of the natural decline in caterpillar populations in Fields 1 and 2, we only examined the effect of insecticides on naturally occurring caterpillar populations in Field 3. We also examined the effect of insecticides on the artificially infested diamondbacks for all three fields.

Although there were naturally occurring populations of diamondback caterpillars in Field 3 infestation levels were very low (<0.5 larvae/plant/plot). Therefore, we only examined the effect of treatments on loopers and imported cabbageworm caterpillars. For imported cabbageworm Entrust and Dipel caused a significant reduction in the number of caterpillars following treatment, however neither of the two alternatives being tested caused reductions relative to the Control (Fig. 6A, Table 7). For loopers, there was no significant difference among the five treatments (Table 7). Interestingly, Entrust only began to cause a reduction of loopers after the second spray and Dipel had no impact (Fig. 6B).

Table 7. Summary statistical analysis for effect of insecticides on individual caterpillar species following two spray treatments.

| | Treatment | Time | Treatment x Time |
|---|---|---|---|
| Imported cabbage worm | $F(4,25) = 4.67$ $p = 0.006$ | $F(4,22) = 14.93$ $p < 0.0001$ | $F(16, 68) = 0.99$ $p = 0.47$ |
| Looper | $F(4,25) = 1.30$ $p = 0.30$ | $F(4,22) = 3.99$ $p = 0.01$ | $F(16, 68) = 1.53$ $p = 0.12$ |

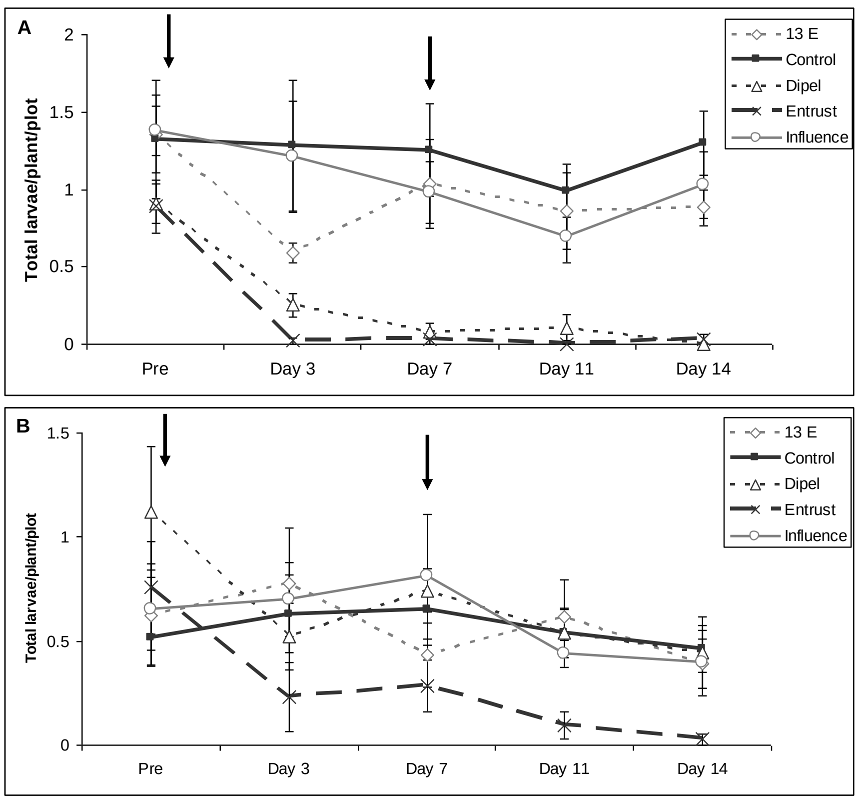


Figure 6. Effect of insecticides on the mean (± s.e.) number of A) imported cabbageworm caterpillars/plant/plot and B) loopers/plant/plot following two sprays. Sprays are indicated with arrows, counts on each spray day were made prior to the spray. Pre-spray levels are from naturally occurring infestation of plots.

Although all three fields were artificially infested with diamondback caterpillars, a sufficient number were recovered from plots, especially Control plots, over the course of the 14 days in Field 3 only. Therefore, results from only this field were analyzed for impact of insecticides on introduced diamondback caterpillars. The effect of the insecticides on the artificially infested diamondback caterpillars was the same as with natural infestations - only Entrust caused significant reductions in caterpillars following each spray and neither Spray oil 13E or Influence had any impact compared to the Control (Fig. 7, Table 8)

Table 8. Summary statistical analysis for effect of insecticides on artificially infested diamondback caterpillars.

| | Repeated measures | Profile Analysis | | | | | |
|---|---|---|---|---|---|---|---|
| Field | | Day 1 | Day 4 | Day 7 | Day 8 | Day 11 | Day 14 |
| 3 | Treatment: $F(4,25)=10.92$, $p<0.0001$ Time: $F(6,20)=36.18$, $p < 0.0001$ Treatment X Time: $F(24,71)=2.07$, $p=0.01$ | Treatment: $F(4,25)=12.05$ $p< 0.0001$ | Treatment: $F(4,25)=13.36$ $p< 0.0001$ | Treatment: $F(4,25)=3.41$ $p=0.02$ | Treatment: $F(4,25)=2.82$ $p=0.05$ | Treatment: $F(4,25)=4.36$ $p=0.008$ | Treatment: $F(4,25)=2.01$ $p=0.12$ |

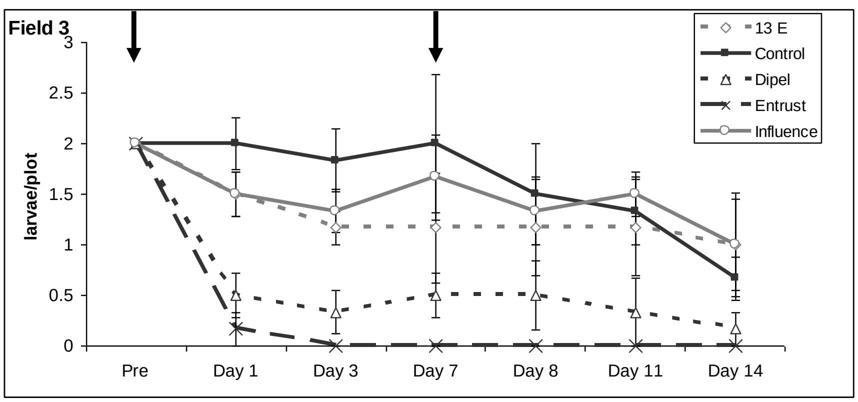


Figure 7. Effect of insecticides on the mean (± s.e.) number of artificially infested diamondback caterpillars following two sprays in Field 3. Sprays are indicated with arrows, counts on each spray day were made prior to the spray. Prior to spray each plot was stocked with two caterpillars.

**Effect on minute and small caterpillars only:** Finally, we examined the effect of sprays on the most susceptible stages of caterpillars - minute and smalls. We only examined the impact of sprays on minute and small caterpillars at Day 3 (% reduction compared to pre-treatment counts), as our trial set up did not prevent moths from laying fresh eggs in plots - resulting in possible "migration" of young caterpillars into plots. Unlike all of our other trial results, there were no significant field effects on the reduction in small and minute caterpillars (Field: $F(2,72) = 1.85$, $p = 0.16$; Treatment X Field: $F(8, 72) = 1.62$, $p = 0.13$). Compared to the Control Entrust, Dipel and Spray oil 13E all caused significant reductions in small and minute larvae 3 days after products were applied (Treatment:

F(4,72) = 10.61, p < 0.0001) (Fig. 8). There was no difference between Influence and the Control; in the Control plots however there was an actual increase in the number of small and minute caterpillars - which could indicate that Influence while not causing mortality to larvae may have a repellent effect on adult moths that deters egg laying.

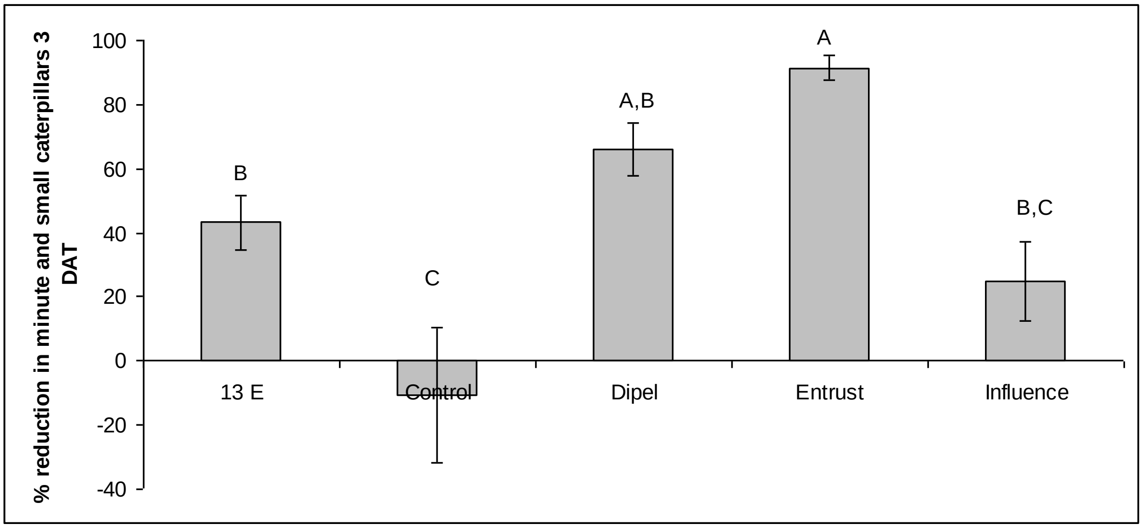


Figure 8. Effect of insecticides on the mean (± s.e.) reduction in number of minute and small caterpillars three days after treatment (DAT) with the first spray. Bars with the same letter are not significantly different based on Tukey Kramer HSD test.

**DISCUSSION & RECOMMENDATIONS**

A major limitation for organic production is the availability of tools for consistent, reliable and cost effective crop protection. Insecticides derived from naturally occurring compounds such as bacteria, mineral oil or plant extracts are approved for organic production and provide growers with the necessary reliability. However, because only a few products are available over reliance on these products can lead to resistance. The objective of this work was to find alternatives to Entrust before resistance becomes an issue for local growers. In other areas Entrust resistance has developed in diamondback moth populations as a result of over reliance (Zhao *et al.* 2006). Alternatives that could be sprayed in rotation with Entrust, will help to delay (and possibly avoid) resistance development and keep Entrust in the grower's management tool box.

When caterpillar populations as whole and plant infestations were looked at neither Spray oil 13E or the garlic-based Influence appeared to have any impact compared to the water only Control. However, Spray oil 13E does seem to be effective at reducing the survival of minute and small caterpillars (Fig. 9). The lack of an effect on the overall population was probably due to no impact on the larger caterpillars, present at the beginning of the trial or the ones that grew over the course of the trial. So, there may be a role for Spray oil 13E as a rotational product with Entrust - in situations where the population is predominately made up of minute and small caterpillars. For example the first spray of the season could be a Spray oil 13E application, with Entrust used as the season progresses and different sizes of caterpillars occur. It is also important to note that both products are very effective for the management of other pests, including scale and aphids (Spray oil 13E) and diseases (Influence), and are therefore good tools for the organic grower. Other options for caterpillar control in organic cole crops that could be explored, in addition to further work on Spray oil 13E, include - biological control, cultural control (trap cropping) and other microbial or botanically based insecticides. While our study confirms that Entrust is still effective, should resistance develop growers would have no options for controlling caterpillar pests, in particular diamondback moth - the most important pest of cole crops globally (Talekar and Shelton 1993).

Biological control of diamondback moth and other pests can be achieved either by conservation of naturally occurring enemies or by introduction of enemies. In local organic cole crop fields, parasitoid wasps arrive in fields several weeks after pests begin to establish on plants (Prasad *et al.* 2009). This lag in natural enemy arrival results in regular aphid outbreaks and similar conditions have been observed for caterpillars. Implementing practices to conserve and increase the population of natural enemies of caterpillar pests could improve biological control. For example, in field trials conducted in Minnesota surrounding cabbage plots with buckwheat (an insectary plant) resulted in increased parasitism of loopers, diamondback and imported cabbageworm caterpillars (Lee and Heimpel 2005). However, parasitism rates were not consistent across years or pest species. Therefore, although conservation biological control would be a good practice to implement levels of control may not be consistent enough to make up for the yield loss due to land set aside for the insectary planting. In a good year, though conservation biological control may help to reduce the number of Entrust applications. Another option for caterpillar control may be to release mass-reared natural enemies. Currently the commercially available species that could be effective for caterpillar control in organic cole crops include the predator *Podisus maculiventris* and the egg parasitoids *Trichogramma* spp. Trials at the local level to develop a cost-effective biocontrol program using these enemies should be explored. Again, biocontrol agents would not have to provide total control of caterpillar pests, only enough to reduce the number of Entrust applications.

Trap cropping of adult moths has also been explored for caterpillar pests of many vegetable crops. For diamondback moth trap cropping with yellow rocket, *Barbarea vulgaris*, has received considerable attention because adult moths are attracted to plants, lay eggs, but larvae do not survive (Badenas-Perez *et al.* 2010). Trap cropping with yellow rocket has been explored as a way to complement insecticide use for diamondback control. A border of yellow rocket will attract adult moths and the bulk of egg laying will occur in the yellow rocket. Since larval survival is so poor on this trap crop, there is little risk of caterpillars moving onto the crop and there is no need for additional controls in the trap crop to kill caterpillars. Trap cropping with yellow rocket should be explored further in local fields.

Finally, other insecticide options for diamondback moth control could be explored. One option that is used effectively in the US for resistance management is XenTari which contains the active ingredient *Baciullus thuringiensis* subsp. *aizawai* or Bta. XenTari is currently registered in the US, for use on cole crops against all of the caterpillar species examined in this study. XenTari is not currently registered in Canada, however research trials are currently being conducted with this product on other crop/pest combinations, which suggests that a Canadian registration may be possible. Such a tool would provide an effective rotational product for Entrust and help to ensure effective caterpillar control for organic cole crop production.

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Appendix I. Field maps

Field 1

| Treatment | Rep # |
|---|---|
| Entrust | 1 |
| Dipel | 1 |
| Influence | 1 |
| Entrust | 2 |
| 13 E | 1 |
| Control | 1 |
| Influence | 2 |
| Dipel | 2 |
| Control | 2 |
| 13 E | 2 |
| Influence | 3 |
| Dipel | 3 |
| Entrust | 3 |
| 13 E | 3 |
| Entrust | 4 |
| Influence | 4 |
| Control | 3 |
| 13 E | 4 |
| Influence | 5 |
| Dipel | 4 |
| Control | 4 |
| Entrust | 5 |
| Dipel | 5 |
| 13 E | 5 |
| 13 E | 6 |
| Dipel | 6 |
| Control | 5 |
| Influence | 6 |
| Entrust | 6 |
| Control | 6 |

→North

Field 2

| Treatment | Rep # |
|---|---|
| Entrust | 1 |
| Dipel | 1 |
| 13 E | 1 |
| Influence | 1 |
| 13 E | 2 |
| Control | 1 |
| Entrust | 2 |
| Dipel | 2 |
| Influence | 2 |
| Dipel | 3 |
| Entrust | 3 |
| Control | 2 |
| Influence | 3 |
| Control | 3 |
| 13 E | 3 |
| Influence | 4 |
| Entrust | 4 |
| 13 E | 4 |
| 13 E | 5 |
| Influence | 5 |
| Dipel | 4 |
| 13 E | 6 |
| Control | 4 |
| Influence | 6 |
| Control | 5 |
| Dipel | 5 |
| Entrust | 5 |
| Control | 6 |
| Entrust | 6 |
| Dipel | 6 |

↑North

Field 3

| Treatment | Rep # |
|---|---|
| Control | 1 |
| Entrust | 1 |
| Dipel | 1 |
| Influence | 1 |
| 13E | 1 |
| 13E | 2 |
| Control | 2 |
| Entrust | 2 |
| Influence | 2 |
| 13 E | 3 |
| Control | 3 |
| 13 E | 4 |
| Entrust | 3 |
| Dipel | 2 |
| Influence | 3 |
| Dipel | 3 |
| Control | 4 |
| Dipel | 4 |
| Influence | 4 |
| Entrust | 4 |
| Control | 5 |
| Dipel | 5 |
| Influence | 5 |
| Entrust | 5 |
| 13 E | 5 |
| Control | 6 |
| Influence | 6 |
| Dipel | 6 |
| Entrust | 6 |
| 13 E | 6 |

↓North