A Novel Attract-and-Kill Strategy to Manage Codling Moth

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In eastern North America, apple orchards are often attacked by several insect pest species in the Lepidopteran family Tortricidae. Codling Moth (CM) is an economically damaging tortricid pest of apple trees. The main damage is caused by caterpillars, which bore into the fruit rendering the fruit unmarketable. Two common management options to control CM are pesticide-based control and mating disruption. However, applications of synthetic insecticides are detrimental to the environment and to non-target species; there is also growing evidence of these pest's developing resistance to various types of insecticides. While the use of synthetic insecticide is not an option for organic growers, mating disruption and biocontrol represent viable options for organic growers. The mating disruption technique utilizes sex pheromone at high density in the orchard to confuse male moths so that they are unable to find and mate with females. For small scale growers, mating disruption is logistically inapplicable and expensive because this strategy is generally appropriate for orchards with areas over 5-6 acres.

In this study, we evaluated an environment friendly attract-and-kill system against CM. Our goal was to attract CM to particular trees by strategically installing lures. This approach is similar to the trap-tree approach developed by UMass for plum curculio. Then, we applied a bioinsecticide (DiPel®) to kill the pest.

Materials and Methods

Lure and trap: The commercial lure Pherocon® Megalure CM Dual 4K (a blend of four plant volatiles) (= Megalure) for codling moth was the 'attract' component. The lures were purchased from Trécé Inc (Adair, OK). All lures were placed inside orange-colored delta-shaped traps (Pherocon VI, Trécé Inc.) with liners coated with adhesive.

Biopesticide: *Bacillus thuringiensis var kurstaki* (DiPel®) was used in the study as the 'kill' component. The commercially available *B.t.* product that was used in this study was DiPel.

Experimental sites: This study was conducted in 6 apple blocks across six orchards in Massachusetts from May 2022 to September 2022. Of these orchards, 3 orchards were certified organic apple blocks and received selected OMRI-listed materials. The other 3 orchards received a standard insecticide spray regime against other key pests.

Attract and Kill system: In each apple block, trees were assigned one of the following four treatments: **(1)** presence of lures (+) and *B.t.* application to that tree only (+), **(2)** presence of lures (+) but no *B.t.* application (-), **(3)** no lures (-) but *B.t.* application (+), and **(4)** no lures (-) and no *B.t.* application (-) (Figure 1). Tree size ranged from small (M.26) to medium (M.7) in size. Each experimental tree was at least 50 meters apart from each other. The experimental design was a ramdomized block design with 3 replications for organic and 3 for conventional orchards.

Figure 1 shows the study layout. The letter 'T' (e.g., T1, T2) represents the experimental trap trees. The numbers around the letters (e.g., 1.1, 1.2, 2.1) indicate trees sampled to determine if there was any spillover effect.

The field study started in the first week of May 2022, with the installation of traps and lures. Each baited tree received one Megalure 4K trap. These lures were hung on the inner side of the orange-colored delta shaped trap. Delta traps were suspended from the upper third of the tree canopy. Sticky liners were removed after the first capture of each moth species to prevent the further killing of moths in the traps. The moths collected from

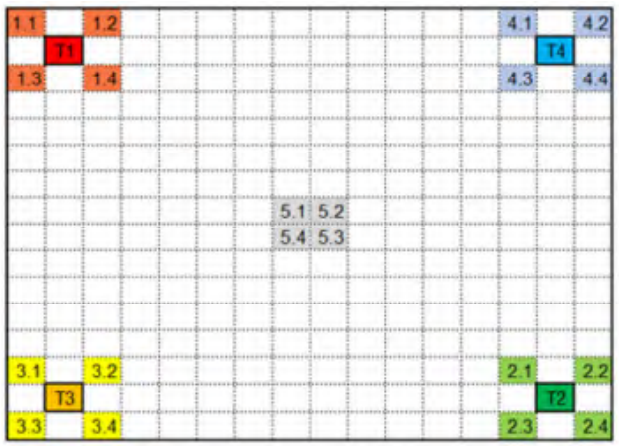

Figure 1. Diagram representing the experimental design. The experimental trees were T1, T2, T3, and T4. Study conducted at 3 organic and 3 conventional orchards in Massachusetts.

the first capture were examined under a dissecting microscope to determine their gender. Additionally, standard sex pheromone lure for codling moth were installed in a separate apple block inside all orchards to monitor the presence of moths. All the lures were replaced after every 4 weeks to insure the sustained flow of odor from the traps. Monitoring traps were checked weekly. The information collected from monitoring trap was used to set up a biofix for CM (Table 1). The first continuous capture of CM was considered as biofix and based on that biofix, degree days were calculated to determine the egg hatch for each generation and time the *B.t* sprays ("Northeast tree fruit management guide", 2022; NEWA degree days calculator).

Table 1. Biofix date (base 50°F of codling moth and timing of *B.t* sprays based on the NEWA degree days model.

Biofix date	First generation sprays	Second generation sprays
May 20	June 1-3 (228-266 DD)	August 8-10 (1568-1621 DD)

Apple trees were sprayed with *B.t.* using a hand-pump backpack sprayer at the rate of 0.65 liter per tree (DiPel standard dose for pome fruits: 2.38 grams of DiPel per liter water) targeting both top and bottom part of leaves. Four adjacent trees were also sprayed to prevent the spillover effect of the traps. Injury data were collected mid-season (June 2022) and at harvest (August 2022). For each block, 100 fruits were visually inspected from each treatment tree (T1, T2, T3, and T4), and 100 fruits from 4 adjacent trees (T1a, T2a, T3a, and T4a), for a total of 800 fruits from each block. All fruits that were suspected of having tortricid injury were brought to the laboratory and dissected for signs of tunneling and presence of larvae.

Results

In this study, during the mid-season sampling (June 2022) there were significant differences across treatments in traps trees in the organic orchard. Trees baited with lure and not sprayed with *B.t.* [T2(+L -Bt)] had significantly higher levels of fruit injury (18.3%) compared to trees baited with lure and *B.t* sprayed [T1(+L +Bt)] (2.7%) and trees without lure and *B.t.* sprayed [T3(-L +Bt)] (0.3%), but were not significantly different than trees without lure and no *B.t.* sprayed [T4(-L -Bt)] (7.3%) during mid-season sampling (Figure 2).

No significant differences were observed in conventional orchards across trap trees. This may be partly due to the standard insecticide spray regime against plum curculio and apple maggot fly. Those sprays were on top of the *B.t.* sprayed as part of this project. Similarly in adjacent trees, there was no significant differences in percentage of fruit injury in either organic or conventional orchards. In organic orchards, adjacent trees, T2a(+L -Bt), had 11% fruit injury on average compared to 5.7% in T4a(-L -Bt) and 3.3% in T1a(+L +Bt). To identify the injury specific to moth species, we collected all the injured fruit and brought them to the lab for further inspection. Upon lab inspection of larvae and raising them in growth chamber, we concluded that all fruit injuries were caused by codling moth. We did not see any injuries by oriental fruit moths or oblique-banded leafrollers in this study.

In the harvest injury assessment (August 2022), we did not see any significant differences in fruit injury among treatments for trap trees and adjacent trees in both organic and conventional

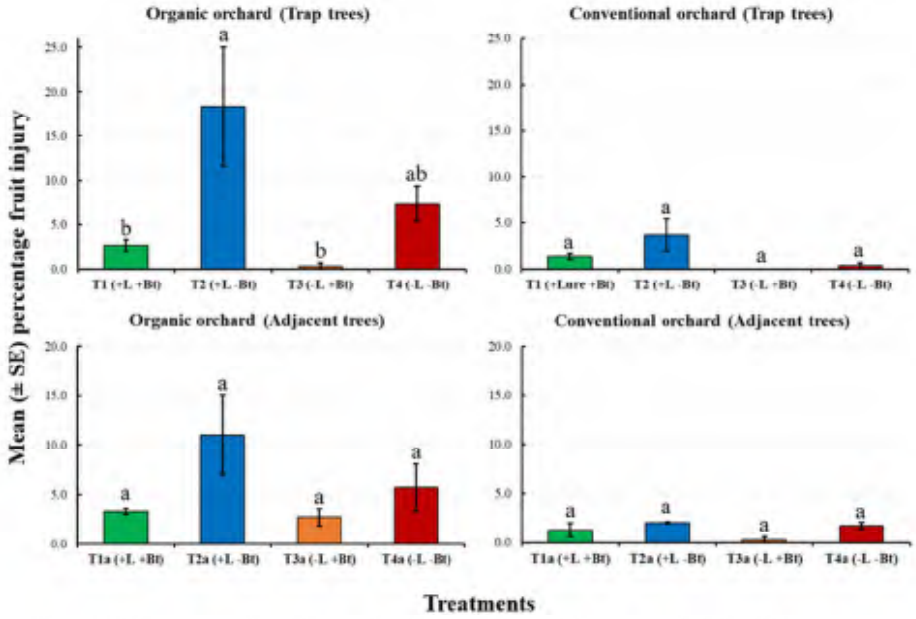

Figure 2: Mean percentage injury on fruits by codling moth larvae sampled at mid-season. Means in same bar graph followed by the same letter do not differ significantly at odds 19:1.

Table 2. Mean percent injury on fruits by codling moth larvae at harvest survey in 3 organic and 3 conventional apple orchards.

Tree type	Treatment	Organic orchard [a]	Conventional orchard [a]
Trap trees	T1 (+L +*Bt*)	1.7 a	0.0 a
	T2 (+L -*Bt*)	9.0 a	1.3 a
	T3 (-L +*Bt*)	0.3 a	0.0 a
	T4 (-L -*Bt*)	0.3 a	0.7 a
Adjacent trees	T1a (+L +*Bt*)	2.0 a	0.3 a
	T2a (+L -*Bt*)	2.3 a	2.0 a
	T3a (-L +*Bt*)	1.3 a	0.0 a
	T4a (-L -*Bt*)	2.3 a	1.0 a

[a] Means in same trees type and type of orchards followed by the same letter do not differ significantly at odds 19:1.

Figure 3: Fruit injury by codling moth from the mid-season sampling.

orchards (Table 2). Interestingly, biological differences were noted for the organic orchard. Trap trees, T2(+L -Bt), got 7.3% more fruit injury on average in organic orchard compared to T1 (+L +Bt) just by not spraying *B.t.* on those trees. While comparing lure baited trap trees to its adjacent trees, it seems that injury is mostly aggregated to baited trees and there is less spillover effect of moths as shown by no significant differences in fruit injury in adjacent trees for both mid-season sampling and harvest sampling.

Conclusion

Odor-baited trap trees baited with Megalure aggregated codling moth injury. By spraying *B.t.* to these baited trees, based on biofix and degree days model, fruit injury was significantly reduced, especially in organic orchards. We did not see any significant differences in conventional orchards partly due to the scheduled insecticide sprays for key pests. These findings can be used to further develop an attract-and-kill system for codling moth. Future studies should evaluate these findings on larger scales and test plant volatiles that are attractive to even more moth species.

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