Research Reports

Optimum Timing of an Application of Corn Oil and *Bacillus thuringiensis* to Control Lepidopteran Pests in Sweet Corn

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Summary. Corn oil and *Bacillus thuringiensis* ssp. *kurstaki* (*Bt*) applied directly into the silk channel of a corn ear has been shown to be an effective pesticide against corn earworm, *Helicoverpa zea* (CEW), and european corn borer, *Ostrinia nubilalis* (ECB). Field studies were conducted in 2000 and 2001 to determine the influence of application timing on ear quality at harvest. Two blocks of corn were planted during each year to observe treatment effects under varying populations of the two insect species. The treatment consisted of 0.5 mL (0.017 fl oz) of food grade corn oil containing a suspension of *Bt* at 0.08 g (0.003 oz) a.i. per ear applied directly into the silk channel at the husk opening. One treatment application was made on each silk day 3 through 11 from first silk; silk day 1 was the first day that 50% or more of ears had 2.5 cm (1 inch) of silk protruding from the husk. One treatment did not receive the oil + *Bt* suspension. All ears were harvested at milk stage, on silk day 25. The number of CEW larvae in treated ears increased with later application days in 2000, but not in 2001. Damage from larval feeding was mainly found near the tip of the ear, and damage ratings were lower compared to untreated ears for all treatment days for both plantings in 2000, and through application day 8 in the late planting of 2001. ECB larvae were reduced for all treatment days in both plantings in 2000 and the late planting of 2001. The percentage of ears rated as marketable (i.e., free of feeding damage) ranged from 71% to 100% in treated plots compared to 30% to 77% in the untreated plots. There was a linear decrease in marketability with later application days in two of the four plantings. The greatest decrease in marketability was after application day 7. Because the oil application affects kernel development at the tip, the length of ear with under-developed kernels, or cone tip, was measured. The number of ears with cone tip decreased linearly with the later application days in all plantings. There was 10% conetip or less after day 7 in 2000 and day 6 in 2001. The best combination of effective insect control resulting in the highest rates of marketable ears with the least degree of cone tip was achieved in this experiment by application of oil + *Bt* suspension on day 7. Year to year variation in the environment would suggest a range from day 6 to 8.

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Most of the sweet corn grown on over 8093.6 ha (20,000 acres) of farmland in New England (New England Agricultural Statistics Service, 2003) is sold fresh through direct sales to consumers or through supermarkets. A barrier for organic growers in these markets is the lack of effective pesticides against ECB and CEW once they enter the silk channel (Hazzard, 1994; Hazzard et al., 2003a). Presence of larvae, feeding damage, or frass make the ears unmarketable to consumers.

Established populations of ECB overwinter in New England, and there are two full generations per year in central and southern New England (Ferro and Weber, 1988). Moths deposit egg masses on the underside of leaves from whorl stage through silking. ECB larvae may move into ears from previous feeding sites in the tassel or from the underside of leaves during silking. Some larvae tunnel through the husk and feed on the side of the ear, while others enter directly through the silk channel and feed on silks and ears.

Migrating flights of CEW reach Massachusetts in July or August, but the time of arrival and the number of moths varies from year to year, depending upon weather patterns. Corn earworm moths prefer to oviposit on silk, and the highest numbers of eggs are laid 3 to 4 d after silk initiation (Lopez, 1978; Nishida and Napompeth, 1974). Eggs hatch in 3 to 7 d, depending on the temperature (Butler, 1976). Larvae enter ears through the silk channel, feeding first on silks within the husk, and then on developing kernels. Depending upon moth activity during silking, newly hatched larvae may enter ears at any time from first silk through harvest.

Foliar sprays of *Bt* are effective against ECB larvae when they are feeding on the outside of the husk or stalk, but do not control CEW or

ECB lavae once they have entered the silk channel of the ear (Hazzard and Mazzola, 1997; Hazzard et al., 1997; Hutchinson and Bartels, 1991; Hutchinson et al., 1992; Linduska, 1990). Early studies (Barber 1938, 1940, 1944; Carruth, 1942; Pepper and Barber, 1940) showed that vegetable or mineral oil (sometimes mixed with a second toxic compound), applied directly into the silk channel in small doses of 0.3 to 1.0 mL (0.01 to 0.03 fl oz), reduced the number of CEW and the damage caused by feeding and frass. This method was not widely adopted due to the lack of an efficient means to apply the treatment and the development and adoption of synthetic insecticides by non organic growers. The invention of a hand-held pump applicator, (Zea-later; Conlet Plastics, New Milford, Conn.), which was recently patented and is now commercially available (Johnny's Select Seeds, Albion, Maine) has renewed interest in the use of oil as a pesticide in corn.

Initial experiments with this oil method showed that several types of mineral, vegetable, or petroleum oils lowered the number of live CEW and ECB larvae found and resulted in 17% to 50% more marketable ears (Hazzard and Gault, 1993; Hazzard and Mazzola, 1997; Siedlecki et al., 1996). The addition of *Bt* to the oil suspension consistently improved the efficacy of corn oil against CEW and ECB in experiments conducted at several locations in Massachusetts and Maine (Hazzard et al., 2004; Hazzard and Mazzola, 1997; Siedlecki, 1996). Applying the treatment on day 5 after first silk had the highest level of control of Lepidopteran pests and damage, compared to earlier and later application days (Siedlecki 1996). Corn oil or a combination of oil and *Bt*, applied on silk day 5, effectively controlled CEW until harvest (day 22 after first silk), even when CEW larvae were already present in the silk channel 2 days before the application, or entered the silk channel up to 14 d after the application (Cook et al., 2003).

In many of these studies, the oil treatment had a secondary effect on the development of kernels at the tip of the ear. This effect has been called tip stunting or cone tip (Carruth, 1942; Siedlecki et. al., 1996) and consists of poorly or completely unfilled kernels in the tip of the ear. Although it has not been quantified, some growers say that conetip is variety specific. In one study, canola oil applied at 1.0 mL per ear reduced total ear length by 1.78 cm (0.7 inch) and the portion of the ear with fully developed kernels by 6% (Hazzard and Gault, 1993). An application of corn oil and *Bt* at 0.3 mL (0.01 fl oz) per ear produced cone tip in 61% of ears, compared with > 80% at 0.6 to 1.2 mL (0.02 to 0.04 fl oz) per ear and 13% in untreated ears (Hazzard et al., 1996). Other studies found that reduction in tip fill was less than 5% or was not significantly different from untreated ears (Hazzard et al., 2003b; Siedlecki 1996). The length of unfilled kernels at the tip was as high as 9% (Cook et al., 2003) when the corn oil and *Bt* was applied on silk day 5. Although cone tip does not usually affect direct sales at farm stands, more stringent standards among wholesale brokers may result in some corn being rejected. This undesirable effect should be minimized to ensure marketability.

The objective of this study was to determine whether an optimum day could be found to apply oil that would be sufficient to control CEW and ECB with the least amount of cone tip.

Materials and methods

FIELD WORK. The sweet corn variety 'Delectable' (The Crookham Co., Caldwell, Idaho) was chosen for the study because it is known to be susceptible to cone tip and because of its popularity among Massachusetts growers and consumers. 'Delectable' is a mid-main season, bicolor, sugar-enhanced corn. Trials were established at the University of Massachusetts Agronomy Farm in South Deerfield, Mass. (lat. 42°28´, long. 72°35´). For each planting (designated as early and late) in each year (2000 and 2001), blocks were planted in rows 91.4 m (300 ft) long and six rows wide on 1.2-m (4 ft) centers. Seeds were planted at a rate of one seed per 22.9 cm (9 inches) with a six-row seeder. The two outer rows in each block served as guard rows, and all first ears on the stalk in the four inner rows were treated. Each block was randomly assigned 10 plots, each 9.1 m (30 ft) long in the row, representing nine treatment days and one untreated plot. The treatment days were 3, 4, 5, 6, 7, 8, 9, 10, and 11 d from first silk [the day when 50% or more of the ears show 2.5 cm or more of silk protruding (Adams and Clark, 1995)]. There were four replications for each treatment. The early and late plantings were planted 2 weeks apart in 2000 and 3 weeks apart in year 2001 in an attempt to coincide with migrating populations of CEW and the second generation of ECB during the silking period.

YEAR 1. The soil type in the research area was an Occum fine sandy loam variant (coarse-loamy, mixed, mesic fluventic dystrocrept). Soil samples were taken in May, 2 weeks after incorporation of a winter rye (*Secale cereale*) cover crop. Ammonium nitrate (33N–0P–0K) was broadcast onto the field at 336.3 $kg \cdot ha^{-1}$ (300 lb/acre) of nitrogen. The planting dates were 9 June (early) and 23 June (late) 2000. The herbicide, metachlor + atrazine (Bicep Magnum Syngenta, Wilmington, Del.) was applied as a preemergence treatment immediately after planting at a rate of 336.2 $mL \cdot ha^{-1}$ (4.6 fl oz/acre).

YEAR 2. Soil samples were taken 2 weeks after rye was incorporated. Ammonium nitrate, 33N–0P–0K, was broadcast onto the field at a rate of 336.3 $kg \cdot ha^{-1}$ of nitrogen. Early and late planting dates in 2001 were 5 and 28 June, respectively. Nitrogen was applied as a side-dress at 112.1 $kg \cdot ha^{-1}$ (100 lb/acre) during the week of 23 July 2001. Metachlor + atrazine was applied as a preemergence herbicide immediately after planting at 336.2 $mL \cdot ha^{-1}$.

An unusual area-wide invasion of fall armyworm (*Pseudaletia unipuncta*) was controlled on 6 July 2001 with spinosad (Spintor 2SC; Dow AgroSciences, Indianapolis) at 131.5 $mL \cdot ha^{-1}$ (1.8 fl oz/acre). On 23 Aug. 2001 when the late planting was at the green tassel stage, *Bacillus thuringiensis* ssp. *kurstaki* (Dipel DF, Valent BioSciences Corp., Richardson, Texas) was applied as a foliar spray against ECB at 2.2 $kg \cdot ha^{-1}$ (2 lb/acre) with a sticking agent (Nu-film, Miller Chemical & Fertilizer, Hanover, Pa.) added at 1.4 $L \cdot ha^{-1}$ (0.15 gal/acre). All other materials and methods for this project were the same for both years and are described below.

Fields were checked weekly for adult CEW and ECB. Heliothis net traps (Scentry Biologicals, Billings, Mont.) were placed in the field to monitor CEW and ECB populations. Two ECB traps, baited with a pheromone lure (Scentry Biologicals) for either the ZI (Iowa) or EII (New York) strain of Ostrinia nubilalis, were placed ≈15.2 m (50 ft) apart in weedy edges of the field. The trap was placed within the experimental area when the corn neared silking stage. Lures were replaced every 2 weeks.

The day that at least 2.5 cm of silks were protruding from husks in 50% of the ears in the experimental area, was designated as silk day 1. Day 1 for the early and late planting in 2000 was 3 and 17 Aug., respectively (14 d apart). For the early and late planting in 2001, 5 and 27 Aug. (22 d apart) were designated as day 1. Any corn stalks with a first ear that was behind or beyond this stage were cut down and left in the field. The remaining plants were assumed to be developmentally uniform.

To prepare the oil and *Bt* mixture, 900 mL (30.4 fl oz) of oil plus an emulsifier [10% Atlox (Uniqema, New Castle, Del.) by volume] were combined with 28.4 g of *Bt* that had been previously mixed with 100 mL (3.4 fl oz) of distilled water. The Zealater delivered 0.5 mL of suspension directly into the silk channel of each corn ear [*Bt* rate: 0.56 $kg \cdot ha^{-1}$ (0.5 lb/acre) in 18.7 $L \cdot ha^{-1}$ (2 gal/acre) of corn oil, assuming 39,537 ears/ha (16,000 ears/acre)]. The mixture was agitated manually and regularly during application to keep material in suspension. The treatments were applied at 1030 HR starting 3 d after first silk and on silk days 4, 5, 6, 7, 8, 9, 10, and 11.

Ears were harvested on silk day 25 for both plantings in both years. At harvest, ears were at milk stage and suitable for direct market sale. In 2000, harvest dates were 28 Aug. (early) and 11 Sept. (late). In 2001, harvest took place on 30 Aug. (early) and 21 Sept. (late).

Twenty-five ears were selected randomly within each plot, placed in paper bags, and stored in a 3.3 °C (37.94 °F) cool room overnight. The next day, the number of live CEW and ECB on each ear was recorded. Any degree of feeding or frass was recorded as damage, but the degree of feeding damage was not assessed. If no entry holes were found in the husk (designated by a 0) or if holes were found above the level of the ear, then larvae were assumed to have entered from the tip. If an entry hole was found in the husk and below the level of the ear (designated by a 1), then it was assumed that the larvae entered through the side of the ear. The damage to the silk or the ear was given a numerical rating based upon where the damage was found (Hazzard et al., 2003b; Siedlecki et al., 1996) as follows: 0 = no damage; 1 = damage in the silk only; 2 = damage to the ear from tip to 2.5 cm below the tip; 3 = damage to the ear from 2.5 to 5.0 cm (2 inches) from the tip; 4 = damage to the ear from 5.0 cm from the tip or longer; and 5 = damage to the shank.

The number of marketable ears was based on a percentage of ears receiving a damage rating of 0. Total ear length and the length of the cone tip were measured. Cone tip (area of undeveloped kernels) was expressed as a percentage of the total ear length.

Design and statistics. The experimental design was a randomized complete block within each planting date and each year with four replications. The data from 25 ears in each plot and four replications (total of 100 ears per treatment day) were analyzed using the general linear model (GLM) of SAS (SAS version 8.2 for Windows; SAS Institute, Cary, N.C.) to evaluate influence of treatment dates on the number of CEW, the number of ECB, and the damage on the ears. Regression analysis (linear, cubic, and quadratic) was used to compare the number of live larvae or their damage with time. Regression was also used to compare percent cone tip and the number of marketable ears with time. The comparison between the treatments and the untreated ears was done using a two-tailed Dunnett's test (Dunnett, 1955). Due to differences in environmental and physical conditions in 2000 and 2001, the data for each year were analyzed separately.

Results

Trap counts. The number of CEW and ECB moths in traps (Table 1) indicated that both insects were present in the experimental area at levels sufficient to cause damage to ears (Ferro and Weber, 1988). CEW counts were higher in 2000, especially during the silking period for the early planting (3 Aug.). For both plantings in 2000 and the late planting in 2001, trap counts indicated that CEW populations were present at a level which, under integrated pest management guidelines, would have required foliar insecticide spray every 4 d to achieve control (Ferro and Weber 1988). For the early planting in 2001, trap counts indicated that a foliar spray would have been necessary every 6 d. Second generation ECB flight began earlier in 2000, but peaked in mid-August in both years.

Corn earworm. Most CEW larvae were found in the silks or in the first 2.5 cm from the tip of the ear. Table 2 depicts the number of larvae, averaged over the two planting dates for 2000 and 2001. The planting date (early or late planting) was nonsignificant for the number of CEW larvae per ear in either year. Application on any treatment day significantly reduced the number of live

Table 1. Weekly total counts of adult male corn earworm and european corn borer moths captured in heliothis net traps[z] (Scentry Biologicals, Billings, Mont.) either within the experimental block or the weedy edges of the same field at the University of Massachusetts Agronomy Farm in South Deerfield, Mass. during the period of time that the experiments were conducted in 2000 and 2001.[y]

Corn earworm				European corn borer			
2000		2001		2000		2001	
Week	Moths captured	Week	Moths captured	Week	Moths captured	Week	Moths captured
20 July	8	18 July	2	20 July	1	19 July	2
27 July	8	26 July	0	27 July	1	26 July	0
3 Aug.	8	2 Aug.	1	3 Aug.	16	2 Aug.	2
10 Aug.	33	9 Aug.	4	10 Aug.	14	9 Aug.	25
17 Aug.	13	20 Aug.	3	17 Aug.	42	16 Aug.	45
29 Aug.	6	28 Aug.	7	29 Aug.	5	23 Aug.	No report
12 Sept.	15	5 Sept.	10			20 Aug.	11

[z]Each of the two european corn borer traps had a different type of synthetic pheromone lure, Sentry ZI or EII. The corn earworm trap was baited with a synthetic Hercon pheromone lure (Great Lakes IPM, Vestaburg, Mich.).
[y]In 2000, silking began on 4 Aug. for early planting and 28 Aug. for late planting. In 2001, silking began 6 Aug. for early planting and 28 Aug. for late planting.

Table 2. The effects of oil + *Bacillus thuringiensis* ssp. *kurstaki* (*Bt*) treatment[z] on the mean corn earworm and european corn borer found in corn ears in 2000 and 2001 at the University of Massachusetts Agronomy Farm in South Deerfield, Massachusetts, and for the significant planting × treatment day interaction in 2001 for european corn borer.

	Larvae per ear (no.)							
			European corn borer					
Day of	Corn earworm				2000		2001	
application	2000[y]	2001[y]	2000[y]	2001[y]	Early[u]	Late[u]	Early[u]	Late[u]
				Treatment				
Untreated	0.17	0.21	0.83	0.32	0.96	0.69	0.15	0.48
3	0.02*[x]	0.02*	0.15*	0.04*	0.08*	0.21*	0.04	0.04*
4	0.03*	0.06*	0.12*	0.11*	0.04*	0.20*	0.12	0.10*
5	0.04*	0.05*	0.13*	0.17	0.10*	0.15*	0.30	0.05*
6	0.02*	0.11	0.14*	0.10*	0.08*	0.20*	0.11	0.09*
7	0.02*	0.06*	0.13*	0.12*	0.08*	0.18*	0.08	0.15*
8	0.04*	0.04*	0.12*	0.18	0.08*	0.15*	0.22	0.13*
9	0.03*	0.13	0.09*	0.14	0.03*	0.15*	0.17	0.10*
10	0.04*	0.05*	0.13*	0.11*	0.05*	0.21*	0.10	0.12*
11	0.07*	0.11	0.13*	0.10*	0.12*	0.13*	0.05	0.14*
Early mean[w]	0.06	0.05	0.16	0.13	---	---	---	---
Late mean	0.03	0.12	0.23	0.14	---	---	---	---
				P value for main effects and interaction				
Planting	0.3847	0.1219	0.4039	0.9115	---	---	---	---
Treatment day	<0.0001	0.0079	<0.0001	0.0240	<0.0001	0.0003	0.0547	0.0053
Planting × treatment	0.4564	0.2151	0.0450	0.0064	---	---	---	---
				Regression[v]				
Linear	0.0190	0.0966	0.08005	0.5500	0.9470	0.5400	0.6797	0.2542
r^2	0.6603	---	---	---	---	---	---	---
m	0.0038	---	---	---	---	---	---	---
x	–0.9855	---	---	---	---	---	---	---
b	0.0076	---	---	---	---	---	---	---
Quadratic	0.1616	0.5259	0.8666	0.0941	0.8649	0.9068	0.1216	0.7007
Cubic	0.2298	0.3597	0.8874	0.6626	0.6474	0.7420	0.5574	0.9058

[z]The treatment (oil + *Bt*) was delivered directly into the silk channel on 3 to 11 d after first silk using a Zea-later (Conlet Plastics, New Milford, Conn.). Oil = food grade corn oil at 0.5 mL (0.017 fl oz) per ear and *Bt* = Dipel DF (Valent Plastics, Richardson, Texas) delivered at 0.56 $kg \cdot ha^{-1}$ (0.5 lb/acre) in 18.7 $L \cdot ha^{-1}$ (2 gal/ acre) of oil.
[y]N = 200. Early and late planting are combined.
[x]*Indicates significance at $P \leq 0.05$ for a two-tailed Dunnett's test comparing each treatment day (day 3 through day 11) to untreated ears.
[w]N = 1000. Mean across all days (including day 0) for each year.
[v]Untreated plots were not included in the regression analysis.
[u]N = 100.

larvae in the ears in 2000 and on days 3, 4, 5, 7, 8, and 10 in 2001 compared to untreated ears. The number of live larvae increased linearly in relation to later application days in 2000, but not in 2001. Overall, there were at least twice as many live CEW per ear in the untreated ears as in the treated ears on any planting date in either year.

EUROPEAN CORN BORER. Most ECB larvae were found in the area 2.5 cm to 5.0 cm from the tip of the ear (Table 2) and were usually accompanied by evidence of a side entry hole in the husk or the shank (Table 3). As with CEW, the main effect, planting date, was nonsignificant (Table 2), but the treatment day was significant for the number of live larvae per ear. Application on any day significantly reduced the number of larvae found per ear in 2000 and on days 3, 4, 6, 7, 10, and 11 in 2001. In 2000, there were at least five times as many ECB larvae per ear in the untreated ears compared to the number found on any treatment day. In 2001, there were at least 1.7 times as many ECB larvae per ear in the untreated ears than any treated ears. In both years, there was a significant planting × treatment day interaction so further separation of means was calculated for each planting date. In 2000, both plantings had significantly reduced levels of ECB damage in all treatment days. In the early planting of 2001, the number of ECB in the untreated ears was low (0.15 per ear) and did not differ significantly from the treated ears, which varied from day to day. In the late planting, however, there were more ECB (0.48 per ear in untreated ears) and the application of oil on any day decreased the number of larvae found in ears. Regression analysis showed a non significant linear, quadratic, or cubic relationship for all planting dates.

FEEDING DAMAGE AT THE TIP OF THE EAR. Most evidence of feeding or frass was observed in the silks or in the first 2.5 cm from the tips of the ears, but some damage was evident further down (Table 3). In both years, all treatment days had significantly less tip damage caused by feeding compared to the untreated ears. There was 4 times more damage per ear in 2000 and at least 1.7 times more damage in 2001.

The planting × treatment day interaction was significant in both 2000 and 2001. Treatment day was significant on all days for both plantings in 2000. Most of the damage was in the silks rather than on the tip. Feeding damage was at least twice as great in

Table 3. The at-harvest effects of oil + *Bacillus thuringiensis* ssp. *kurstaki* (*Bt*) treatment[z] treatment on corn tip and side damage[y] from corn ear worm and european corn borer feeding in 2000 and 2001 at the University of Massachusetts Agronomy Farm in South Deerfield, Mass. Significant planting × treatment day interactions are also shown for the tip damage rating in 2000 and 2001.

Day of application	Tip (silk and kernels) Mean damage rating per ear						Side (husk) Mean no. of husks with feeding damage	
			2000[x]		2001[x]			
	2000[w]	2001[w]	Early	Late	Early	Late	2000[w]	2001[w]
			Treatment					
Untreated	1.09	0.86	1.46	0.71	0.50	1.21	0.84	0.67
3	0.14*	0.12*	0.08*	0.20*	0.12	0.11*	0.49	0.22
4	0.12*	0.22*	0.11*	0.13*	0.32	0.11*	0.37	0.27
5	0.15*	0.17*	0.20*	0.09*	0.23	0.11*	0.38	0.27
6	0.18*	0.34*	0.09*	0.27*	0.13	0.54*	0.41	0.64
7	0.12*	0.25*	0.10*	0.14*	0.26	0.24*	0.38	0.53
8	0.23*	0.45*	0.22*	0.24*	0.36	0.53*	0.47	0.52
9	0.19*	0.48*	0.09*	0.29*	0.35	0.60	0.51	0.81
10	0.15*	0.34*	0.21*	0.08*	0.19	0.48*	0.64	0.51
11	0.27*	0.44*	0.30*	0.23*	0.19	0.68	0.72	0.70
Early mean[v]	0.29	0.27	---	---	---	---	0.21	0.30
Late mean	0.24	0.46	---	---	---	---	0.83*	0.72
			P values for main effects and interaction					
Planting	0.6353	0.0918	---	---	---	---	0.0404	0.1824
Treatment day	<0.0001	0.0002	<0.0001	0.0006	0.0394	0.0006	0.3765	0.0058
Planting × treatment	0.0004	0.0156	---	---	---	---	0.9081	0.0764
			Regression[u]					
Linear	0.1154	0.0017	0.0980	0.5953	0.5669	0.0012	0.0920	0.0002
r^2	---	0.8341	---	---	---	0.8537	---	0.7957
m	---	0.0395	---	---	---	0.0727	---	0.0600
x	---	0.0956	---	---	---	2.8012	---	–0.02778
b	---	0.0357	---	---	---	–0.1309	---	0.0767
Quadratic	0.7045	0.3691	0.4531	0.8178	0.1496	0.7696	0.1713	0.1750
Cubic	0.7646	0.6496	0.3158	0.5488	0.5032	0.8569	0.8765	0.8131

[z]The treatment (oil + *Bt*) was delivered directly into the silk channel on 3 to 11 d after first silk using a Zea-later (Conlet Plastics, New Milford, Conn.). Oil = food grade corn oil at 0.5 mL (0.017 fl oz) per ear and *Bt* = Dipel DF (Valent Plastics, Richardson, Texas) delivered at 0.56 $kg·ha^{-1}$ (0.5 lb/acre) in 18.7 $L·ha^{-1}$ (2 gal/acre) of oil.
[y]Damage to silk or kernels was rated based upon the location of feeding damage: as follows: 0 = no damage; 1 = damage in the silk only; 2 = damage to the ear from tip to 2.5 cm (1 inch) below the tip; 3 = damage to the ear from 2.5 to 5.0 cm (2 inches) from the tip; 4 = damage to the ear from 5.0 cm from the tip or longer; and 5 = damage to the shank. Husks with one or more entry holes were rated as 1; those with no husk damage were rated as 0.
[x]N = 100.
[w]N = 200. Early and late planting combined.
[v]N = 1000. Mean across all days (including untreated plots) for each year.
[u]Untreated plots were not included in the regression analysis.
*Significant at $P \leq 0.05$ for a two-tailed Dunnett's test comparing each treatment day (day 3 through day 11) to untreated plots.

the untreated ears as in treated ears on any day that oil + *Bt* was applied.

In 2001, tip damage was not significantly different from the untreated ears in the early planting, but was significant on treatment application dates 3, 4, 5, 6, 7, 8, and 10 in the late planting. Evidence of damage increased linearly with the later treatment days in the late planting.

Feeding damage on the side of the husk. A numerical rating of 1 was assessed if an entry hole was found in the husk somewhere along the side of the ear. It was observed that this damage was caused almost exclusively by ECB, not CEW. The mean number of husks with side damage were significantly different in the two planting dates only in 2000 (Table 3), when the number with damage was four times higher in the late planting (0.83/ear) compared to the early planting (0.21/ear). This corresponds with the higher ECB numbers found in the late planting. The Dunnett's test indicated that husk damage was not significantly different in the untreated ears compared to any treatment day in either year. Planting date was not significant, but treatment day was significant in 2001. The number of ears with entry holes in the side of the husk increased linearly with the later application days.

Marketable ears. If there was any evidence of feeding or frass on the ear, then the ears were considered unmarketable, regardless of how much damage was actually found (Table 4). Only those ears that received a damage rating of 0 were counted as marketable.

Applying the oil treatment on any day produced more marketable ears than not applying the treatment. The percent marketable ears was 85% or higher for all treatment days in 2000 compared to 47% marketable in untreated ears, and 82% or higher in 2001, compared to 65% marketable ears in untreated plots. The percent marketable ears was somewhat variable in 2000, but decreased with the later treatment dates in 2001, going below 88% on days 8, 9, 10, and 11.

In the early planting of 2000, the percent marketable ears was 30% in

Table 4. The at-harvest effects of oil + *Bacillus thuringiensis* ssp. *kurstaki* (*Bt*) treatment[z] on percent marketable corn ears at harvest, averaged over both planting dates in 2000 and 2001 and for each planting date (early and late) in both years at the University of Massachusetts Agronomy Farm in South Deerfield, Massachusetts. Marketable ears were based on a damage rating of 0 (no damage).

Day of application	Marketable (%) 2000[x]	2001[x]	2000[y] Early	2000[y] Late	2001[y] Early	2001[y] Late
	Treatment					
Untreated	47	65	30	63	77	53
3	92*[x]	95*	96*	87*	94*	95*
4	94*	90*	95*	93*	85	94*
5	94*	92*	90*	97*	89*	95*
6	89*	88*	93*	84	95*	80*
7	98*	90*	94*	100*	90*	89*
8	88*	82*	86*	90*	88	75
9	89*	82*	90*	88*	87	76
10	94*	85*	92*	96*	92*	78
11	85*	82*	85*	85	92*	71
	P values for main effects and interaction					
Planting	0.4972	0.1141	---	---	---	---
Treatment day	0.0001	0.0001	0.0001	0.0061	0.0078	0.0018
Planting × treatment	0.0189	0.0395	---	---	---	---
	Regression[w]					
Linear	0.1219	0.0016	0.0172	0.8062	0.9232	0.0009
r^2	---	–0.8803	---	---	---	–0.8923
m	---	–1.55	---	---	---	3.1167
x	---	63.9120	---	---	---	34.1312
b	---	98.1833	---	---	---	105.4833
Quadratic	0.2917	0.2344	0.9312	0.2713	0.4027	0.8411
Cubic	0.7589	0.6104	0.4720	0.9387	0.9049	0.7410

[z]Treatment (oil + *Bt*) was delivered directly into the silk channel on days 3 to 11 after first silk using a Zea-later (Conlet Plastics, New Milford, Conn.). Oil = food grade corn oil at 0.5 mL (0.017 fl oz) per ear and *Bt* = Dipel DF (Valent Plastics, Richardson, Texas) delivered at 0.56 kg·ha^{-1} (0.5 lb/acre) in 18.7 L·ha^{-1} in 2 gal/acre of oil.
[y]N=100.
[x]N = 200. Early and late plantings are combined.
[w]Untreated plots are not included in the regression analysis.
*Significant at $P \leq 0.05$ for a two-tailed Dunnett's test comparing ears from each treatment day (3 through 11) to the untreated ears.

the untreated ears, but ranged from 85 to 96% in the treated ears. In the 2000 late planting, only 63% of the untreated ears were marketable and the treated ears were between 84 and 100% marketable. The early planting of 2001 had the highest percentage of untreated, but marketable ears (77%) of the four planting dates – treated ears were between 85 and 95 % marketable. The number of untreated ears that were marketable in 2001 was only 53 % compared to 71 to 95% marketable in treated ears. Two plantings (early 2000 and late 2001) showed a negative linear relationship between the day of treatment application and marketability.

PERCENT CONE TIP. All main effects and their interactions were significant in 2000, but only the treatment day was significant in 2001 (Table 5). The percent cone tip decreased linearly with the day of treatment application in both years. Percent cone tip was not significantly different from the untreated control by day 10 in 2000 and by day 7 in 2001. In 2000, the degree of cone tip on treated ears was not significantly different from the degree of cone tip on untreated ears by day 10 in the early planting and by day 9 in the late planting and the decrease in cone tip was linear for both plantings.

Discussion

As shown by the varying levels of marketability and damage in the untreated ears, Lepidopteran pressure differed among the four planting dates. Though CEW populations were low relative to those that may be present in some years or in other regions (Hazzard et al., 2003b), they were high enough to cause significant damage to the ears. European corn borer was present in varying numbers in all plantings. Thus, our objective of testing the effect of application timing under varying pest conditions was met.

Based on the data for this study alone, and looking solely at damage, one could conclude from this study that there was little advantage to applying treatments on earlier versus later treatment dates. Only in one of the four plantings (2001, late planting) was there an increase in tip damage level with time. Three of four plantings (2000, early and late and 2001, late) showed significantly lower damage for all treatment dates. The one (2001, early) which did not show significant improvement also had the lowest insect pressure from both CEW and ECB and the least tip damage to the untreated ears.

Fresh-market standards, both wholesale and retail, demand that at least 90% or more of ears be free of larvae and their damage (Hazzard, 1997; Hazzard et al., 2003). In the four plantings, the highest percentage of marketable ears, and the highest number of treatments with marketability significantly greater than the untreated ears (18 out of 20 data points), was found among ears with treatments applied on day 7 or before (Table 4). After day 7, a higher proportion of treatments resulted in marketability that was not significantly better than untreated (7 out of 16 data points), and marketability was below 80% in over half the treatments. The planting with the lowest marketability ratings after day 7 (late planting, 2001) was also the planting which had the highest number of both CEW and ECB (Table 2, Table 5). Other research is consistent with this finding, except that it suggested that applying oil after day 5 of silking resulted in a lower percentage of marketable ears and higher damage ratings (Cook et. al., 2003; Siedlecki et al., 1996). Previous experiments have shown that oil + *Bt* kills small CEW larvae that are already in the ear prior to application, as well as those larvae that enter after application (Cook et al., 2003). CEW eggs hatch in 2.9 to 4.5 d under the summer temperature conditions that occur in Massachusetts; thus when adult moths are present and

Table 5. The effects of oil + *Bacillus thuringiensis* ssp. *kurstaki* (*Bt*) treatment[z] on percent unfilled kernels[y] at harvest at the tip (cone tip) found per ear for the ten treatment levels, averaged over both planting dates in 2000 and 2001 and for each planting date (early and late) in 2000 at the University of Massachusetts Agronomy Farm in South Deerfield, Mass.

Day of application	Cone tip (%)			
		2000		
	2000[x]	Early[w]	Late[w]	2001[x]
		Treatment		
Untreated	2.62	1.60	3.65	0.53
3	15.59*[w]	11.05*	20.14*	13.69*
4	16.21*	13.49*	18.92*	9.38*
5	15.48*	12.32*	18.65*	7.37*
6	12.92*	10.89*	14.56*	8.26*
7	11.13*	9.82*	12.45*	2.56
8	9.71*	8.52*	10.89*	2.27
9	8.07*	7.61*	8.53	1.42
10	6.26	6.85*	5.66	1.05
11	5.59	4.68	6.51	1.62
		Main effects and interaction		
Planting	0.0240	---	---	0.4159
Treatment	<0.0001	**	**	<0.0001
Planting × treatment	0.0162	---	---	0.3319
		Regression[v]		
Linear	<0.0001	<0.0001	<0.0001	<0.0001
r^2	–0.9818	–0.9295	–0.9829	–0.9206
m	–0.1465	–0.9532	–1.9702	–1.5193
x	8.5142	7.4931	14.0564	11.0884
b	21.4704	16.14	26.7145	15.9264
Quadratic	0.3754	0.0679	0.8790	0.4735
Cubic	0.0786	0.2288	0.1525	0.1907

[z]Treatment (oil + *Bt*) was delivered directly into the silk channel days 3 to 11 after first silk using a Zea-later (Conlet Plastics, New Milford, Conn.). Oil = food grade corn oil at 0.5 mL (0.017 fl oz) per ear and *Bt* = Dipel DF (Valent Plastics, Richardson, Texas) delivered at 0.56 kg·ha^{-1} (0.5 lb/acre) in 18.7 L·ha^{-1} (2 gal/acre) of oil.
[y]Percent cone tip = (length of the ear with unfilled tip ÷ length of the whole ear) × 100.
[x]N = 200. Early and late planting are combined.
[w]N = 100.
[v]Untreated ears were not included in the regression analysis.
*Significant at $P \leq 0.05$ for a two-tailed Dunnett's test comparing treatment day 3 through day 11 to the untreated ears.

laying eggs as soon as silk is present, larvae could be expected to enter ears any time after about day 4 (Lopez, 1978). ECB may enter at any time during silking, whenever larvae are searching for protected feeding sites within the ear. Given the efficacy found even in later oil treatments in these studies, some mortality probably occurred when oil was applied after larvae entered the ear. This could account for some of the variation in damage from day to day.

The oil application reduced ECB as well as CEW, similar to the findings in other studies (Hazzard et al., 2004). Visual observations showed that even though there was an entry hole in the side of the ear, there was not always damage to the ear at the entry hole. Possible explanations for this are that some ECB backed out of the husk once they encountered the oil barrier and did not feed on the ears, or that they ingested a toxic dose and were killed prior to entering. Overall, however, side damage was not reduced by the oil application regardless of application day (Table 3). Hazzard (1997) showed that a higher percentage of clean ears were found when *Bt* was used as a foliar spray in addition to the oil + *Bt* direct silk application. In the late 2001 planting, where a pre-silk foliar application of *Bt* was used, side damage increased with late application days. This supports the hypothesis that the presence of oil and *Bt* underneath the husk earlier during silk development (in the silk channel or coating some part of the developing ear) influences either the behavior or the survival of ECB larvae.

A grower's objective is to maximize the likelihood that the oil will be effective in achieving greater than 90% marketable ears and to minimize the cone tip effect. The consistent linear relationship between application day and proportion of cone tip indicates that later applications minimize this negative effect. Significantly higher proportions of cone tip occurred through application day 7 in all four plantings, and up to 4 d longer (until day 11) in one planting.

Cone tip was present to a small extent (0.5% to 3.6% of the ear) in untreated corn. While the expectation for modern cultivars is that kernels should develop all the way to the tip, this is not always achieved. Observations in published (Cook et al., 2003) and unpublished studies indicate that oil treatment after day 5, usually resulting in ~9% or less cone tip, generally results in a cone tip that is acceptable to consumers at farm stands, but there are no known scientific reports indicating whether or not this level of cone tip would be allowed in the wholesale market. In this study, 10% or less cone tip occurred between day 4 and day 10, with the mean approximately on day 7. The variation is probably due to environmental factors such as soil moisture or air temperature as this affects both silk growth and pollination (Daynard and Duncan, 1969; Duncan, 1975). This experiment and other work (Carter, unpublished) showed that application of oil prior to day 5 could cause a drastic effect on kernel development of the ear. The silk did not detach from the kernel in these undeveloped kernels. This may indicate that either pollination and/or fertilization was inhibited, as silks normally detach after fertilization (Duncan, 1975).

Silks begin to dry and turn dark after about day 6 or 7. It becomes more difficult to apply the oil into the silk channel evenly. It also takes more time to insert the applicator squarely into the opening in the husk. It takes ≈8 h to apply the oil treatment to an acre of corn (D. Kaplan, personal communication). While growers report that the sales offset labor costs, anything that decreased accuracy or the increased the time it takes to apply the oil would discourage the grower from using this method of insect control.

If the percent cone tip for the untreated ears is subtracted from percent cone tip of the treated ears, then day 6 was roughly the day that 10% or less cone tip was achieved. The average ear length for 'Delectable' is 17.8 cm (7 inches) so 10% of an undeveloped tip is 1.8 cm (0.71 inch). Growers at farm stands in New England have been able to explain cone tip to the satisfaction of consumers, especially if they understand that it is a result of growing corn organically (Hazzard, 1994). Growers have to weigh the expected damage that would result from poor control by applying oil several days after larvae have had time to feed on the ear versus the degree of cone tip found on the ear. Growers who sell through direct marketing and often have an ongoing relationship with their customers are aware of the degree of tolerance their customers have for imperfect ears.

No one can predict the level of infestation of ECB and CEW nor the environmental conditions that affect silk growth and pollination from one year to the next. It is critical to monitor populations locally through trapping or at least regionally with county or state entomologists and growers. But based on all measured parameters, and accounting for some environmental variability, a single, direct silk application of oil + *Bt* on days 6 to 8 from first silk will effectively decrease the damage to the ear caused by ECB and CEW, and increase marketability while minimizing cone tip on the ear.

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