Impact of Combining Planting Date and Chemical Control to Reduce Larval Densities of Stem-Infesting Pests of Sunflower in the Central Plains

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ABSTRACT The guild of stem-infesting insect pests of sunflower, *Helianthus annuus* L., within the central Plains is a concern to producers chiefly due to losses caused by plant lodging from the sunflower stem weevil, *Cylindrocopturus adspersus* (LeConte) (Coleoptera: Curculionidae), and *Dectes texanus texanus* LeConte (Coleoptera: Cerambycidae). The incidence of a root boring moth, *Pelochrista womonana* (Kearfott) (Lepidoptera: Tortricidae), also has increased. Experiments were conducted in three locations in Colorado and Kansas during 2001–2003 to investigate the potential of combining planting date and foliar and seed treatment insecticide applications to lower insect stalk densities of these three pests. The impact of these strategies on weevil larval parasitoids also was studied. Eight sunflower stem weevil larval parasitoid species were identified. All were Hymenoptera and included the following (relative composition in parentheses): *Nealiolus curculionis* (Fitch) (42.6%), *Nealiolus collaris* (Brues) (3.2%) (Braconidae), *Quadrastichus ainsliei* Gahan (4.2%) (Eulophidae), *Eurytoma tylodermatis* Ashmead (13.1%) (Eurytomidae), *Neocatolaccus tylodermae* (Ashmead) (33.7%), *Chlorocytus* sp. (1.6%), *Pteromalus* sp. (0.5%) (Pteromalidae), and *Eupelmus* sp. (1.0%) (Eupelmidae). The results from this 3-yr study revealed that chemical control was often reliable in protecting the sunflower crop from stem pests and was relatively insensitive to application timing. Although results in some cases were mixed, overall, delayed planting can be a reliable and effective management tool for growers in the central Plains to use in reducing stem-infesting pest densities in sunflower stalks. Chemical control and planting date were compatible with natural mortality contributed by *C. adspersus* larval parasitoids.

KEY WORDS sunflower, *Cylindrocopturus adspersus*, *Dectes texanus*, *Pelochrista womonana*, pest management

The sunflower stem weevil, *Cylindrocopturus adspersus* (LeConte) (Coleoptera: Curculionidae), is a cultivated sunflower, *Helianthus annuus* L., pest that has caused yield losses in North Dakota (Charlet et al. 1997, Knodel and Charlet 2002). Since the early 1990s, damage has been reported and population densities of stem weevils have been increasing in the central Plains of eastern Colorado, western Kansas, and southwestern Nebraska (Armstrong 1996, Charlet et al. 2002, Charlet and Glogoza 2004). Adult sunflower stem weevils emerge from overwintered stalks in May to June, and females lay their eggs at the base of sunflower stems. Larvae feed apically within the stems and then descend to the lower portion of the stalk or root crown by late August and excavate overwintering chambers by chewing cavities into the stem cortex. If larval populations in a plant are high, the stem, weakened by tunneling, pith destruction, or overwintering chambers, may break, causing a loss of the entire plant before harvest. In addition, the sunflower stem weevil has been implicated in the epidemiology of sunflower fungal pathogens, including Phoma black stem, *Phoma macdonaldii* Boerma, and charcoal rot, *Macrophomina phaseolina* (Tassi) Goid, diseases that contribute to stalk rot and that may predispose plants to lodging (Gaudet and Schulz 1981, Yang et al. 1983, Charlet et al. 1997). Earlier work by Charlet et al. (1985) found that average stalk densities of 37 larvae resulted in 28% plant lodging before harvest. Stalk breakage or lodging due to the sunflower stem weevil is most severe during drought stress or when high winds occur as plants are drying before harvest (Rogers and Jones 1979, Charlet 1987b). Several species of parasitic wasps attack the sunflower stem weevil larvae with the species richness

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greater in the central High Plains than in the northern Plains (Charlet 1999, Charlet et al. 2002).

A longhorned beetle, *Dectes texanus texanus* LeConte (Coleoptera: Cerambycidae), has been recognized as a pest of sunflower since the early 1970s when it caused considerable damage in south central Texas (Rogers 1977, 1985b). It also was reported as an important pest of soybean (Hatchett et al. 1975, Michaud and Grant 2005, Niide et al. 2006). High populations of this pest were evident in stalks from the central Plains extending into South Dakota in 2003 (Charlet and Glogoza 2004). The larvae feed and tunnel in the petioles, then into stem pith, and finally move to the base of the plant to overwinter. In late summer, the mature larvae girdle the inside of the lower stalk or root crown, move below the girdle, and pack frass into the tunnels. Stalks often break at the point of girdling, leaving the larva protected in its frass-packed tunnel during the winter (Rogers 1985b, Charlet et al. 1997).

The incidence of a root boring moth, *Pelochrista womonana* (Kearfott) (Lepidoptera: Tortricidae), also has increased in the past 5 yr based on recovery of larvae from the lower stalk and root area in sunflower from the central Plains (L.D.C., unpublished data). This insect was previously noted as a pest of sunflower in the southern Plains, but an injury threshold has not been determined (Rogers 1979, Rogers 1985a).

The objective of this study was to explore the potential of combining cultural and chemical control strategies to reduce stem weevil densities and thus reduce losses caused by lodging in sunflower. We investigated the impact of different planting dates with both foliar and seed treatment insecticide applications on *C. adspersus* populations, and, because of the increasing incidence of a longhorned beetle and root-boring moth, larval numbers of these pests in the stalks and root crowns also were compared. Models for degree-day prediction of weevil emergence have been developed for both the northern and central Plains (Charlet 1987a, Armstrong 1996), but they have not been used for insecticide treatment timing. Trials at one site (Colby, KS) included foliar chemical application based on both plant stage and degree-day models to determine efficacy in managing stem weevil stalk numbers. The impact of these management strategies on weevil larval parasitoids also was studied.

Materials and Methods

Plots were established at three locations: 1) the USDA–ARS Central Great Plains Research Station, Akron, CO; 2) a site near Goodland, KS; and 3) the Northwest Research Extension Center, Kansas State University, Colby. Triumph oilseed hybrid 652 was used in all trials at each location. The experimental design was a split plot with planting date as the main effect and insecticide treatments as subplots. Locations and years were assumed to be random factors and planting dates were considered fixed effects within the analysis of variance (ANOVA) (McIntosh 1983). Means were compared by using the Fisher protected least significant difference (LSD) test (Carmer and Walker 1985) at $P < 0.05$. In 2001, plots were seeded at Akron on 23 May, 6 June, and 18 June, at Goodland on 23 May, 4 June, and 14 June, and at Colby on 11 May, 5 June, and 22 June. In 2002, plots were seeded at Akron on 21 May and 6 and 18 June, at Goodland on 22 and 31 May and 10 June, and at Colby on 10 and 28 May and 6 June. In 2003, plots were seeded at Akron on 21 May and 6 and 20 June, at Goodland on 19 and 29 May and 9 June, and at Colby on 13 May and 2 and 24 June. Plots were four rows wide by 8 m in length, with rows 76 cm apart, and plants spaced 30.5 cm apart within rows; ≈ 54,000 plants per ha. The treatments included a foliar insecticide application of carbofuran at a rate of 0.56 kg ([AI])/ha at vegetative growth stage V8 (Schneiter and Miller 1981) and at either growth stage V12 or to coincide with 581 degree-days (base of 6°C beginning 1 January). This was estimated to be the time when 90% of the weevils had emerged as adults in this region (Armstrong 1996). Degree-day timing of treatment could not be used in 2001 because the targeted number of units was reached before plants had emerged or were seeded, so treatment timing was based on plant growth stage at all locations. Because of similar circumstances at both Akron and Goodland in 2002 and 2003, treatment timing also was based on plant growth stage. However, treatments comparing insecticide timing based on plant stage and degree-days were conducted at Colby in 2002 and 2003. A seed treatment of thiamethoxam (Cruiser, Syngenta Crop Protection, Greensboro, NC) was included in the trials at a rate of 0.2 mg ([AI])/seed in 2002 and at 1.0 mg ([AI])/seed in 2003. All treatments were compared over the three planting dates and were replicated four times.

The degree of infestation was measured by comparing the number of sunflower stem weevil larvae per stalk. Five stalks (≈50 cm of basal length plus the root crown) per row (total of 20 per treatment) were removed after plants had senesced and sent to L.D.C.'s laboratory in Fargo, ND. The sunflower stalks were harvested at Akron on 8 October 2001, 25 October 2002, and 14 November 2003, at Goodland on 10 October 2001, on 26 November 2002, and 5 December 2003, and at Colby on 4 and 23 October 2001, on 8, 9, and 16 October 2002, and on 10, 18, and 23 September and 16 October 2003. Stalks were held in the cold (5°C) for a minimum of 6 wk and then split. The numbers of weevil larvae in each stem were counted. Counts of *P. womonana* and *D. texanus* larvae also were made. Weevil larvae were reared individually in small, multichambered plastic units at 24 ± 2°C, 50–60% RH, and a photoperiod of 15:9 (L:D) h for emergence of adults or parasitoids (Charlet 1983). Weevil larvae were held until eclosion of adults, emergence of parasitoids, or death. Dead larvae were not dissected to determine the presence of parasitoids. Percentage of parasitization was calculated as the number of parasitoids recovered divided by the total sunflower stem weevil larvae reared. Parasitoids were identified by comparing them to specimens previously determined by specialists at the USDA–ARS Systematic Entomology Laboratory (Beltsville, MD). Voucher specimens were placed in L.D.C.'s sunflower insect collection (USDA–ARS Northern Crop Science Laboratory, Fargo, ND) and in the North Dakota State Insect Reference Collection, Department of Entomology, North Dakota State University, Fargo, ND. The ANOVA option of the GLM procedure was used to compare larval numbers among the different treatments for each study year. Means were separated using the LSD test ($P < 0.05$). Percentages were arc sine transformed before analysis (SAS Institute 2001).

Results

The effect of treatments, combined for years, locations, and planting dates, showed no significant difference ($F = 3.30$; df = 3, 6, $P = 0.10$) among the two insecticide timings or the seed treatment in reducing the density of stem weevil larvae, compared with the control (Table 1). However, planting date as a main effect was significant ($F = 22.51$; df = 2, 4; $P < 0.01$); the mean number of weevil larvae per stalk decreased from 31 to 10 as planting date was delayed. A nonsignificant ($F = 1.03$; df = 6, 11; $P > 0.10$) planting date by treatment interaction revealed that treatment differences were not affected by planting date. A significant four-way interaction of year, location, planting date, and treatment ($F = 4.32$; df = 16, 1,656; $P < 0.0001$) indicated that the impact of the treatments on weevil numbers within stalks at each planting date was dependent on environment effects unique to each location and year.

In 2001, stem weevil larval populations were lowest at Akron with densities ≈25% of the other two sites (Table 1). Delayed planting reduced densities of weevil larvae at two locations. Insecticide applications reduced the number of stem weevil larvae within sunflower stalks for most of the planting dates at all three locations. Overall, difference in weevil control at the three locations and planting dates did not seem to be affected by the plant stage in which the treatments were applied. The average separation between the two stages when treatments were applied was 7 d, probably an adequate time interval to see differences, if present. Colby was the only location showing better control of larvae when insecticide was applied at the V12 stage.

Stem weevil densities in 2002 were highest at Goodland with a mean of 54.9 larvae per stalk in the untreated check at the early planting date, followed by 43.1 larvae per stalk at Colby, and then 25.4 larvae per stalk at Akron (Table 1) and again decreased with later seeding dates. Foliar insecticide treatments, with one exception, were only effective in reducing weevil numbers at Colby. It is possible that low soil moisture at both Akron and Goodland prevented uptake and movement of the carbofuran within the plant and thus reduced the efficacy of the insecticide treatments in killing larvae within the plants. Rainfall in July 2002 was 37.9 mm at Colby compared with 2.5 and 1.3 mm at Akron and Goodland, respectively. For the first planting date at Goodland, the application of carbo-

Table 1. Impact of different treatments and planting dates on number of sunflower stem weevil larvae in stalks of sunflower at Akron, CO, Goodland, KS, and Colby, KS, 2001–2003

Planting	Treatment	No. *C. adspersus* larvae per stalk (mean ± SE)									
		2001			2002			2003			Mean
		Akron	Goodland	Colby	Akron	Goodland	Colby	Akron	Goodland	Colby	
Early	Control	11.2 ± 2.0aA	45.5 ± 5.9aA	38.6 ± 4.7aA	25.4 ± 4.8aA	54.9 ± 8.6aA	43.1 ± 5.0aA	31.1 ± 4.5aA	46.1 ± 4.8aA	47.5 ± 5.9aA	38.8 ± 2.0a
	V8	7.5 ± 1.8ab	24.8 ± 3.0b	16.8 ± 2.4b	37.6 ± 5.7a	42.2 ± 5.4ab	10.1 ± 1.6b	30.8 ± 5.8a	30.3 ± 4.2b	34.1 ± 6.3b	25.4 ± 1.7a
	V12	4.6 ± 1.1b	19.0 ± 4.4b	8.1 ± 2.0c	31.5 ± 4.6a	31.5 ± 5.1b		31.8 ± 5.5a	50.2 ± 5.3a		25.9 ± 2.0a
	Seed				32.9 ± 5.3a	42.8 ± 6.5ab	46.2 ± 4.2a	16.6 ± 3.0b	54.0 ± 5.5a	18.0 ± 2.7c	34.9 ± 2.3a
Mean											31.2 ± 1.0a
Mid	Control	7.5 ± 1.5aA	36.7 ± 6.6aA	29.9 ± 3.8aA	7.6 ± 1.4aB	37.2 ± 6.8abAB	43.8 ± 5.5aA	17.0 ± 2.7aB	22.6 ± 2.7aB	8.9 ± 2.2aB	22.8 ± 1.6a
	V8	3.3 ± 0.6b	8.5 ± 2.3b	13.5 ± 1.8b	10.0 ± 2.4ab	40.8 ± 5.5a	7.4 ± 2.5c	10.5 ± 2.1b	19.8 ± 1.9a	6.0 ± 1.3a	12.9 ± 1.2a
	V12	1.2 ± 0.3b	4.9 ± 1.1b	5.7 ± 1.7c	13.8 ± 2.7b	31.6 ± 5.2ab		10.0 ± 2.2b	22.1 ± 2.9a		13.0 ± 1.3a
	Seed				5.7 ± 1.1a	23.6 ± 3.2b	30.3 ± 4.9b	5.8 ± 1.4b	23.9 ± 2.2a	6.8 ± 1.7a	15.4 ± 1.4a
Mean											16.3 ± 0.7b
Late	Control	6.5 ± 1.4aA	11.3 ± 2.3aB	32.1 ± 3.2aA	6.2 ± 1.5aB	19.1 ± 3.3bB	23.5 ± 4.4aB	4.8 ± 1.1abC	10.5 ± 1.4aC	1.4 ± 0.7aB	12.9 ± 1.1a
	V8	2.1 ± 0.6b	5.0 ± 1.5b	12.4 ± 2.4b	10.1 ± 2.2a	20.3 ± 4.9b	3.0 ± 0.7c	6.0 ± 1.5a	7.9 ± 1.2a	0.6 ± 0.1a	7.7 ± 0.8a
	V12	2.9 ± 1.2b	6.8 ± 1.7ab	6.0 ± 1.6b	6.2 ± 1.1a	36.8 ± 5.9a		2.3 ± 1.0bc	1.6 ± 0.5b		8.7 ± 1.3a
	Seed				7.4 ± 1.2a	25.9 ± 2.3ab	15.5 ± 1.9b	1.8 ± 0.5c	11.4 ± 3.3a	0.1 ± 0.1a	10.3 ± 1.1a
Mean											9.9 ± 0.5c

Means followed by the same lowercase letter in a column within a planting date are not significantly different ($P < 0.05$; LSD). Means followed by the same uppercase letter in a column are not significantly different ($P < 0.05$; LSD) from corresponding controls among planting dates; 20–40 stalks examined per treatment at each location per year.

furan at V12 reduced the density of weevils below that of control plants. However, at the third planting date, the numbers of weevils from this same treatment were actually higher than in the control. The seed treatment seemed to be ineffective in lowering densities of weevil larvae. However, at the Colby location, stem weevil larval populations were somewhat reduced by the seed treatments at the second and third planting dates compared with the control. Reasons for this are unclear and the reduction in weevil density was still less than from the foliar treatments.

In 2003, densities of stem weevils within stalks were similar at both Goodland and Colby but higher than at Akron (Table 1). Planting date comparisons revealed, as in previous years, that stem weevil populations decreased with later planting. At Akron, both foliar carbofuran applications reduced weevil densities from the second planting date. At Goodland, the V8 treatment reduced weevil larvae in stalks from the first planting date, but not from the second or third dates. The V12 treatment was effective in reducing weevil numbers in stalks only from the third planting date. At Colby, carbofuran applied at V8 reduced stem weevil densities only from the first planting date. Again, these inconsistencies may have been caused by low soil moisture levels that prevented uptake and movement of the carbofuran within plants and thus reduced the efficacy of the insecticide in killing larvae. Rainfall was low at all three locations; totals for July were only 10.7, 22.9, and 25.1 mm at Colby, Akron, and Goodland, respectively. The seed treatment was more effective than in previous years in lowering densities of weevil larvae at two of the locations. Part of the reason could be due to an increase in the amount of chemical applied to the seed [0.2 mg ([AI])/seed in 2002 and 1.0 mg ([AI])/seed in 2003]. At both Akron and Colby, the seed treatment reduced weevil numbers within stalks at most of the planting dates. The lack of a response at the Goodland site is unclear, because soil moisture conditions were similar at this location.

Treatments, among the two insecticide timings or the seed treatment, combined for years, locations, and planting, did not significantly reduce ($F = 1.22$; df = 3, 6; $P > 0.10$) the density of *D. texanus* larvae compared with the control (Table 2). In addition, planting date as a main effect was nonsignificant ($F = 3.39$; df = 2, 4; $P > 0.10$. Treatment was not affected by planting date, based on a nonsignificant ($F = 0.83$; df = 6, 11; $P > 0.10$) planting date by treatment interaction. These results are likely due to low larval densities at all sites. The data did not indicate that populations were increasing over years, especially at Goodland and Colby.

In 2001, *D. texanus* numbers per stalk were extremely low at all three locations, preventing any meaningful comparison among the different treatments (Table 2). In 2002, longhorned beetle densities were again very low, making it difficult to evaluate either treatments or planting date at both Akron and Goodland. Although the stalk density of *D. texanus* larvae at Colby was somewhat higher than at the other two sites, a significant reduction in numbers was only

Table 2. Impact of different treatments and planting dates on number of *D. texanus* larvae in stalks of sunflower at Akron, CO, Goodland, KS, and Colby, KS, 2001–2003

Planting	Treatment	No. *D. texanus* larvae per stalk (mean ± SE)									
		2001			2002			2003			Mean
		Akron	Goodland	Colby	Akron	Goodland	Colby	Akron	Goodland	Colby	
Early	Control	0aA	0aA	0aA	0aA	0.3 ± 0.1aA	0.3 ± 0.1aA	0aA	0.3 ± 0.1aA	0.4 ± 0.1aA	0.1 ± 0.0a
	V8	0a	0a	0a	0.1 ± 0.1a	0.1 ± 0.0ab	0.3 ± 0.1a	0.1 ± 0.1a	0b	0.4 ± 0.1a	0.1 ± 0.0a
	V12	0a	0a	0a	0.1 ± 0.1a	0b		0.1 ± 0.1a	0b		0a
	Seed				0a	0.2 ± 0.1a	0.4 ± 0.1a	0.1 ± 0.1a	0.1 ± 0.1ab	0.6 ± 0.1a	0.2 ± 0.0a
Mean											0.1 ± 0.0a
Mid	Control	0aA	0aA	0.1 ± 0.1aA	0.1 ± 0.1aA	0.2 ± 0.1aA	0.3 ± 0.1aA	0.1 ± 0.1aA	0.1 ± 0.1aAB	0.6 ± 0.1aA	0.1 ± 0.0a
	V8	0a	0a	0a	0.1 ± 0.1a	0.1 ± 0.1a	0.1 ± 0.1a	0.1 ± 0.1a	0.1 ± 0.1a	0.4 ± 0.1a	0.1 ± 0.0a
	V12	0.1 ± 0.1a	0a	0a	0a	0.1 ± 0.1a		0a	0.1 ± 0.1a		0a
	Seed				0a	0.2 ± 0.1a	0.4 ± 0.1a	0a	0.2 ± 0.1a	0.6 ± 0.6a	0.2 ± 0.0a
Mean											0.1 ± 0.0a
Late	Control	0aA	0aA	0aA	0aA	0aB	0.4 ± 0.1aA	0aA	0aB	0.1 ± 0.1aB	0a
	V8	0a	0a	0a	0.1 ± 0.1a	0.1 ± 0.1a	0.1 ± 0.1b	0a	0a	0.2 ± 0.1a	0a
	V12	0a	0.1 ± 0.1a	0a	0.1 ± 0.1a	0a		0a	0a		0a
	Seed				0a	0a	0.2 ± 0.1ab	0a	0a	0.1 ± 0.1a	0.1 ± 0.0a
Mean											0a

Means followed by the same lowercase letter in a column within a planting date are not significantly different ($P < 0.05$; LSD). Means followed by the same uppercase letter in a column are not significantly different ($P < 0.05$; LSD) from corresponding controls among planting dates; 20–40 stalks examined per treatment at each location per year.

evident with the foliar treatment at the third planting date. In 2003, densities of *D. texanus* larvae were too low for meaningful comparisons among treatments and planting date at both Akron and Goodland. Although the density of longhorned beetles at Colby was somewhat higher than at the other two sites, significant differences were not evident among the foliar or seed treatments.

The means of the two insecticide timings, the seed treatment, and the controls, combined for years, locations, and planting date, were not significantly different ($F = 1.30$; df = 3, 6; $P > 0.10$) in reducing the density of *P. womonana* larvae compared with the control (Table 3). The planting date effect overall also was not significant ($F = 2.04$; df = 2, 4; $P > 0.10$), although it seemed that moth larval densities decreased as seeding date was delayed. Although the treatment by planting date interaction was not significant ($F = 1.69$; df = 6, 11; $P > 0.10$), the year by treatment ($F = 6.10$; df = 5, 16; $P = 0.0024$) and location by treatment ($F = 19.03$; df = 6, 16; $P < 0.0001$) interactions were both significant, indicating that treatments were more effective in some environments than in others.

In 2001, densities of *P. womonana* in sunflower stalks were higher at Colby than at the other two locations, and, in the absence of insecticides, densities were highest in the first planting date. The foliar insecticide application at the (V)8 stage reduced moth larval densities for the early planting date at Akron. At Colby, both foliar treatments were effective at the early and late planting dates, whereas only the treatment at V12 was effective at the middle planting date. There was no significant difference between treatment times in numbers of moth larvae per plant at either location.

There were fewer root boring moth larvae at Colby in 2002 in stalks from the second and third planting date compared with the first planting date. In addition, foliar treatment with carbofuran significantly reduced larval densities at all three planting dates. As was the case with stem weevil, the seed treatment did not seem to reduce larval populations at any location. There was no significant difference in moth density in the seed treatment stalks for any of the three planting dates compared with the control.

In 2003, the numbers of *P. womonana* larvae at Colby decreased with delay in planting date. At Akron, foliar treatment at the V12 stage lowered the number of moth larvae, but only at the first planting date. None of the foliar or seed treatments were effective at either the Goodland or Colby locations in reducing density of *P. womonana* larvae compared with the control plots.

Eight species of parasitoids were identified from 28,323 sunflower stem weevil larvae reared during the 3 yr of the study. All were Hymenoptera as follows (relative composition shown in parentheses): *Nealiolus curculionis* (Fitch) (42.6%), *Nealiolus collaris* (Brues) (3.2%) (Braconidae), *Quadrastichus ainsliei* Gahan (4.2%) (Eulophidae), *Eurytoma tylodermatis* Ashmead (13.1%) (Eurytomidae), *Neocatolaccus tylo-*

Table 3. Impact of different treatments and planting dates on number of *P. womonana* larvae in stalks of sunflower at Akron, CO, Goodland, KS, and Colby, KS, 2001–2003

Planting	Treatment	No. *P. womonana* larvae per stalk (mean ± SE)									
		2001			2002			2003			Mean
		Akron	Goodland	Colby	Akron	Goodland	Colby	Akron	Goodland	Colby	
Early	Control	0.5 ± 0.1a A	0.1 ± 0.1aA	3.1 ± 0.6aA	0.1 ± 0.1aA	0.3 ± 0.1aA	5.8 ± 1.0aA	0.3 ± 0.1aA	0.5 ± 0.2aA	2.5 ± 0.5aA	1.5 ± 0.2a
	V8	0.1 ± 0.1b	0.2 ± 0.1a	0.9 ± 0.2b	0.1 ± 0.1a	0.6 ± 0.2a	2.5 ± 0.4b	0.1 ± 0.1ab	1.1 ± 0.3a	3.3 ± 0.8ab	0.9 ± 0.1a
	V12	0.3 ± 0.1ab	0.1 ± 0.1a	0.5 ± 0.2b	0.1 ± 0.1a	0.2 ± 0.1a		0.1 ± 0.1b	0.9 ± 0.3a		0.3 ± 0.1a
	Seed				0.1 ± 0.1a	0.6 ± 0.3a	6.8 ± 0.8a	0.1 ± 0.1ab	0.9 ± 0.2a	4.5 ± 1.0b	2.2 ± 0.3a
Mean											1.2 ± 0.1a
Mid	Control	0.2 ± 0.2aAB	0.3 ± 0.1aA	1.7 ± 0.4aA	0.1 ± 0.1aA	0.2 ± 0.1abA	3.2 ± 0.6aB	0.2 ± 0.1aA	0.9 ± 0.3aA	2.4 ± 0.4aA	1.0 ± 0.1a
	V8	0.2 ± 0.2a	0b	1.4 ± 0.4ab	0.1 ± 0.1a	0.3 ± 0.1ab	0.9 ± 0.3b	0a	1.1 ± 0.3a	1.7 ± 0.4a	0.6 ± 0.1a
	V12	0.1 ± 0.1a	0.1 ± 0.1ab	0.6 ± 0.2b	0.1 ± 0.1a	0b		0.1 ± 0.1a	1.0 ± 0.3a		0.3 ± 0.1a
	Seed				0.1 ± 0.1a	0.4 ± 0.2a	3.9 ± 1.0a	0.2 ± 0.1a	0.9 ± 0.2a	2.4 ± 0.4a	1.2 ± 0.2a
Mean											0.8 ± 0.1a
Late	Control	0.1 ± 0.1aB	0.2 ± 0.1aA	1.9 ± 0.3aA	0.1 ± 0.1aA	0.3 ± 0.1aA	2.0 ± 0.4aB	0.1 ± 0.1abA	0.3 ± 0.2aA	0.2 ± 0.1aB	0.6 ± 0.1a
	V8	0.1 ± 0.1a	0.1 ± 0.1a	0.5 ± 0.2b	0.1 ± 0.1a	0.3 ± 0.2a	0.5 ± 0.2b	0.2 ± 0.1a	0.2 ± 0.1a	0.3 ± 0.1a	0.2 ± 0.0a
	V12	0.1 ± 0.1a	0.1 ± 0.1a	0.6 ± 0.2b	0.1 ± 0.1a	0.3 ± 0.1a		0.1 ± 0.1ab	0.3 ± 0.1a		0.2 ± 0.0a
	Seed				0.1 ± 0.1a	0.2 ± 0.1a	2.3 ± 0.5a	0b	0.3 ± 0.1a	0.3 ± 0.1a	0.5 ± 0.1a
Mean											0.4 ± 0.0a

Means followed by the same lowercase letter in a column within a planting date are not significantly different ($P < 0.05$; LSD). Means followed by the same uppercase letter in a column are not significantly different ($P < 0.05$; LSD) from corresponding controls among planting dates; 20–40 stalks examined per treatment at each location per year.

dermae (Ashmead) (33.7%), *Chlorocytus* sp. (1.6%), *Pteromalus* sp. (0.5%) (Pteromalidae), and *Eupelmus* sp. (1.0%) (Eupelmidae). These parasitoid species have previously been reported attacking the sunflower stem weevil in the central Plains (Armstrong 1997, Charlet et al. 2002, Charlet and Aiken 2005). The lowest species diversity occurred at Akron with four species recovered. The Goodland and Colby locations were similar with seven and eight species collected, respectively. At both Akron and Colby, *N. curculionis* was the dominant parasitoid species, but was replaced by *N. tylodermae* at the Goodland site.

Treatment effect combined over years, locations, and planting dates showed no significant difference ($F = 0.39$; df = 3, 6; $P > 0.10$) among the two insecticide timings or the seed treatment on sunflower stem weevil larval parasitization compared with the control (Table 4). Differences among the three planting dates were not significant ($F = 3.66$; df = 2, 4; $P > 0.10$). A nonsignificant ($F = 0.40$; df = 6, 11; $P > 0.10$) planting date by treatment interaction indicated that treatment was not affected by planting date. However, the year by treatment ($F = 3.34$; df = 5, 13; $P = 0.037$) interaction was significant, indicating that the impact of treatments on parasitization was not consistent in all years.

In 2001, parasitization rates were higher at Colby that at the other two locations (Table 4). Foliar treatments had an impact on parasitization only at Goodland, with lower parasitism in plots treated at the V12 stage at the second and third planting dates. Parasitization of sunflower stem weevil larvae was similar for all planting dates at the three locations.

Sunflower stem weevil parasitization was very low at Akron in 2002, with less than 1% parasitism in all treatments at all three planting dates. Colby had higher rates of parasitization than the other two sites, but rates were less than the previous year. There were no significant differences in stem weevil parasitism among treatments on any planting date at any site in 2002.

The treatments had no impact on parasitization of *C. adspersus* at Colby (Table 4). However, results were mixed at the other locations. The two foliar treatments reduced parasitization at Akron, but only for the second planting date. Although parasitization of weevil larvae was reduced by both foliar and seed treatments compared with the control at Goodland within the first planting date, in the second and third dates larval parasitization in the control was actually lower than some of the treatments.

In trials at Colby, neither of the two treatment timings were effective in reducing sunflower stem weevil larvae in the stalks within each planting date, compared with the control when combined over years, planting date, and treatment ($F = 1.91$; df = 4, 4; $P = 0.273$) (Table 5). However, a significant year by treatment ($F = 37.74$; df = 2, 317; $P < 0.0001$) interaction indicated that the effectiveness of treatments differed over the two years. At Colby, all chemical treatments effectively reduced stem weevil larvae in stalks in 2002; however, no impact from chemical

Table 4. Impact of different treatments and planting dates on *C. adspersus* larval parasitism in stalks of sunflower at Akron, CO, Goodland, KS, and Colby, KS, 2001–2003

Planting	Treatment	*C. adspersus* larval % parasitization (mean ± SE)									
		2001			2002			2003			Mean
		Akron	Goodland	Colby	Akron	Goodland	Colby	Akron	Goodland	Colby	
Early	Control	2.6 ± 1.1aAB	1.8 ± 0.7aA	7.1 ± 1.4aA	0.3 ± 0.3aA	0.6 ± 0.3aA	5.1 ± 1.5aA	2.0 ± 1.2aA	14.2 ± 3.5aA	1.3 ± 0.7aA	4.0 ± 0.6a
	V8	0.7 ± 0.5a	2.0 ± 1.7a	6.5 ± 1.4a	0a	1.2 ± 0.5a	4.5 ± 2.9a	0.6 ± 0.5a	5.5 ± 1.8b	1.5 ± 0.5a	2.6 ± 0.5a
	V12	4.0 ± 2.5a	1.1 ± 0.6a	7.5 ± 1.5a	0.1 ± 0.1a	1.5 ± 0.8a		0.7 ± 0.7a	6.0 ± 1.1b		3.1 ± 0.5a
	Seed				0.4 ± 0.4a	0.9 ± 0.5a	4.1 ± 0.9a	2.9 ± 1.7a	6.0 ± 1.0b	1.0 ± 0.5a	2.5 ± 0.4a
Mean											3.1 ± 0.3a
Mid	Control	10.5 ± 4.6aA	5.1 ± 1.3aA	19.2 ± 3.6aA	0aA	0.7 ± 0.4aA	3.3 ± 0.7aA	4.4 ± 1.4aA	4.2 ± 1.7bB	2.3 ± 1.3aA	5.7 ± 0.8a
	V8	1.8 ± 1.8a	3.1 ± 2.1ab	18.6 ± 3.2a	0a	1.4 ± 0.8a	2.7 ± 1.5a	0.9 ± 0.7b	13.1 ± 3.1a	1.8 ± 1.0a	5.5 ± 0.9a
	V12	0a	0.9 ± 0.6b	20.3 ± 5.7a	0.6 ± 0.4a	0.4 ± 0.3a		1.3 ± 0.8b	7.1 ± 1.9ab		5.0 ± 1.2a
	Seed				0a	0a	3.5 ± 1.3a	3.5 ± 2.5ab	12.7 ± 3.9a	0a	3.6 ± 1.0a
Mean											5.1 ± 0.5a
Late	Control	0.8 ± 0.8aB	7.6 ± 3.4aA	16.9 ± 4.5aA	0aA	2.3 ± 1.4aA	3.6 ± 2.0aA	3.8 ± 2.9aA	4.8 ± 2.1bB	0aA	5.0 ± 1.0a
	V8	0a	3.4 ± 2.0ab	8.9 ± 3.9a	0a	1.0 ± 0.6a	5.0 ± 3.0a	0a	5.6 ± 2.3b	0a	2.6 ± 0.7a
	V12	1.6 ± 1.6a	0b	12.6 ± 4.1a	0a	3.5 ± 2.1a		0a	1.9 ± 1.9b		3.3 ± 1.0a
	Seed				0a	0.4 ± 0.3a	3.1 ± 1.3a	0a	16.0 ± 4.1a	0a	4.4 ± 1.2a
Mean											3.9 ± 0.5a

Means followed by the same lowercase letter in a column within a planting date are not significantly different ($P < 0.05$; LSD). Means followed by the same uppercase letter in a column are not significantly different ($P < 0.05$; LSD) from corresponding controls among planting dates; percentages were transformed before analysis, and 20–40 stalks examined per treatment at each location per year.

Table 5. Effect of timing of foliar treatments on mean number of sunflower stem weevil in sunflower at different dates of planting at Colby, KS, 2002–2003

Planting time	Treatment	*C. adspersus* larvae mean ± SE		
		2002	2003	Mean
Early	Control	43.1 ± 5.0a	47.5 ± 5.9a	45.3 ± 3.8a
	V8	10.1 ± 1.6b	34.1 ± 6.3a	22.4 ± 3.8a
	581DD	11.1 ± 2.2b	43.7 ± 5.2a	28.2 ± 3.9a
Mid	Control	43.8 ± 5.5a	8.9 ± 2.2a	24.4 ± 4.0a
	V8	7.4 ± 2.5b	6.0 ± 1.3a	6.7 ± 1.4a
	581DD	3.2 ± 0.9b	6.9 ± 1.8a	5.0 ± 1.0a
Late	Control	23.5 ± 4.4a	1.4 ± 0.7a	12.5 ± 2.8a
	V8	3.0 ± 0.7b	0.6 ± 0.2a	1.8 ± 0.4a
	581DD	3.9 ± 0.9b	0.5 ± 0.2a	2.2 ± 0.5a

Means followed by the same letter in a column within each planting date are not significantly different ($P < 0.05$; LSD); 20–40 stalks examined per treatment each year.

Table 7. Effect of timing of foliar treatments on mean number of *P. womonana* in sunflower in different dates of planting at Colby, KS, 2002–2003

Planting time	Treatment	*P. womonana* larvae mean ± SE		
		2002	2003	Mean
Early	Control	5.8 ± 1.0a	2.5 ± 0.5a	4.1 ± 0.6a
	V8	2.5 ± 0.4b	3.3 ± 0.8a	2.9 ± 0.4a
	581DD	1.3 ± 0.3b	2.5 ± 0.5a	1.9 ± 0.3a
Mid	Control	3.2 ± 0.6a	2.4 ± 0.4a	2.7 ± 0.4a
	V8	0.9 ± 0.3b	1.7 ± 0.4a	1.3 ± 0.3a
	581DD	1.1 ± 0.3b	1.8 ± 0.4a	1.4 ± 0.3a
Late	Control	2.0 ± 0.4a	0.2 ± 0.1a	1.1 ± 0.3a
	V8	0.5 ± 0.2b	0.3 ± 0.1a	0.4 ± 0.1a
	581DD	0.4 ± 0.2b	0.2 ± 0.1a	0.3 ± 0.1a

Means followed by the same letter in a column within each planting date are not significantly different ($P < 0.05$; LSD); 20–40 stalks examined per treatment each year.

treatment or planting date was observed in 2003 (Table 5). It is possible that the relatively low rainfall in 2003 (only 10.7 mm in July) limited uptake of the insecticide in the plants, reducing the impact on larvae within the stalks. There were no significant differences between the two treatment timings among the early, mid, or late planting dates.

As in the case of the stem weevils, treatments were ineffective in reducing the density of *D. texanus* in the stalks over all three planting dates ($F = 0.38$; df = 4, 4; $P = 0.816$) (Table 6). A nonsignificant year by treatment interaction ($F = 0.64$; df = 2, 317; $P = 0.526$) indicated the response was consistent over the 2 yr. Between the two years of the study, the only indication of a treatment impact was the lower number of *D. texanus* larvae in the plots treated with carbofuran at the V8 stage during the third planting date in 2002 (Table 6). There was no difference between the two treatment timings either year.

Trial results from insecticide treatment timing for management of *P. womonana* were similar to those for the sunflower stem weevil; neither insecticide timing reduced root moth number in stalks within a planting date compared with the control when combined over years, planting date, and treatment ($F = 0.83$; df = 4, 4; $P = 0.567$) (Table 7). However, a significant year by treatment interaction ($F = 15.98$; df = 2, 317; $P < 0.0001$) indicated that the effectiveness of treatments was not consistent over years. Treatment had no impact at any planting date in 2003, but all treatments effectively reduced *P. womanana* larval numbers in stalks in 2002 at all three dates of planting. This difference may have been due to reduced absorption and translocation of compounds to larval feeding sites because of lower rainfall in 2003 (10.7 mm) compared with 2002 (37.8 mm). No significant differences were noted between the two treatment timings among the early, mid, or late planting dates (Table 7).

Table 6. Effect of timing of foliar treatments on mean number of *D. texanus* in sunflower at different dates of planting at Colby, KS, 2002–2003

Planting time	Treatment	*D. texanus* larvae mean ± SE		
		2002	2003	Mean
Early	Control	0.3 ± 0.1a	0.4 ± 0.1a	0.4 ± 0.1a
	V8	0.3 ± 0.1a	0.4 ± 0.1a	0.4 ± 0.1a
	581DD	0.2 ± 0.1a	0.5 ± 0.1a	0.4 ± 0.1a
Mid	Control	0.3 ± 0.1a	0.6 ± 0.1a	0.4 ± 0.1a
	V8	0.1 ± 0.1a	0.4 ± 0.1a	0.3 ± 0.1a
	581DD	0.3 ± 0.1a	0.4 ± 0.1a	0.4 ± 0.1a
Late	Control	0.4 ± 0.1a	0.1 ± 0.1a	0.2 ± 0.1a
	V8	0.1 ± 0.1b	0.2 ± 0.1a	0.1 ± 0.0a
	581DD	0.2 ± 0.1ab	0.1 ± 0.1a	0.1 ± 0.1a

Means followed by the same letter in a column within each planting date are not significantly different ($P < 0.05$; LSD); 20–40 stalks examined per treatment each year.

Discussion

Sunflower stem weevil larval density within sunflower stalks over all environments (locations and years) showed a significant decline as planting date was delayed (Table 1). Lower populations of *C. adspersus* are important in reducing larval feeding injury in the stem pith and vascular tissue. In addition, fewer larvae constructing overwintering chambers in the stalk help to maintain the plant's structural integrity, thereby reducing plant lodging (Charlet et al. 1997, Charlet and Aiken 2005). The data confirmed earlier studies in Texas (Rogers et al. 1983), North Dakota (Oseto et al. 1982), and Kansas (Charlet and Aiken 2005) showing that altered planting date, especially delayed planting, could be an effective cultural management strategy to reduce populations of *C. adspersus.* Furthermore, planting date did not seem to adversely affect parasitization of weevil larvae as revealed in the lack of any significant rate change over the three dates (Table 4). Over the 3 yr, only in 1 yr at two different locations was there an indication that parasization of *C. adspersus* declined as planting was delayed. Thus, the parasitoids seem to be active and capable of attacking their host over an extended period. The absence of a planting date effect on larval parasitism also was reported earlier in confection and oilseed sunflower (Charlet and Aiken 2005).

The effect of planting date was less evident in impact on numbers of *D. texanus* or *P. womonana* in sunflower stalks; and, overall there was no significant difference among the three dates of planting. Even across all locations and years there were only differences in *D. texanus* populations among the planting dates at one location over 2 yr and at another location in just 1 yr. Likewise, *P. womonana* numbers only declined as planting date was delayed in 2 yr at one location, and only in 1 yr at another. The lack of response was likely because of low population levels for both species, although longhorned beetle numbers per stalk did exhibit an increase over time (Tables 2 and 3). *P. womomana* overwinters in the sunflower roots (Rogers 1979, 1985a), and it is likely that counts for this insect underestimated population levels, because some individuals may have remained in the soil after stalk collection. Earlier research in Texas did reveal that manipulating planting dates effectively reduced sunflower infestation by both *D. texanus* (Rogers 1985b) and *P. womanana* (Rogers 1985a).

Changes in sunflower planting date also have been shown to be effective with other sunflower pests, including the sunflower beetle, *Zygogramma exclamationis* (F.) (Charlet and Knodel 2003); the banded sunflower moth, *Cochlyis hospes* Walsingham (Oseto et al. 1989); and the red sunflower seed weevil, *Smicronyx fulvus* LeConte (Oseto et al. 1987), without significant loss of yield. However, in the case of the seed weevil, earlier planting was more effective in preventing plant injury. Other studies also have shown the efficacy of altered planting dates in reducing insect populations in a crop in more than one region. Showler et al. (2005) recently showed that delayed planting could assist in boll weevil suppression in cotton grown under subtropical conditions as well as in the temperate Rolling Plains of Texas. As noted by Kennedy and Storer (2000), crop phenology can be a determinant of colonization and population growth for some pest species. Thus, altering the planting time can offer a crop habitat less attractive and less suitable for pest development and may reduce the infestation of a particular field and subsequent crop damage and yield loss.

This study did not adequately demonstrate the potential effectiveness of treatments in lowering stem weevil densities in stalks within planting dates, probably because of significant location and year interactions. However, for most locations, and for many of the years, the foliar application of carbofuran did reduce populations of *C. adspersus* significantly compared with untreated plants (Table 1). The effectiveness of the application was evident at all three planting dates. Other studies also demonstrated the efficacy of a foliar treatment in reducing densities of weevils in stalks in Texas and Colorado, but these studies examined only one planting date (Rogers et al. 1983, Armstrong et al. 2004). Although in a few instances, one treatment timing was superior to another in reducing weevil numbers, the data did not differentiate between the V8 or V12 stage for applications targeting *C. adspersus.* The efficacy of the seed treatment was unclear because rates (0.2 mg and 1.0 mg ([AI])/seed] were different between years, although the higher rate did provide some control at one location in 2003. In that environment, seed treatment was effective with all three planting dates, and it also reduced densities at a second location on the first planting date when populations were high. More work is needed to determine if seed treatments have the potential utility for management of the sunflower stem weevil.

The treatments did not impact parasitism of stem weevil larvae, except at a few locations and years, and in some cases larvae from treated plots had higher parasitization rates (Table 4). Although one location (Akron) had a much lower diversity of parasitoid species than the other two locations, there did not seem to be any corresponding differences in rates of parasitization. Thus, there was no apparent impact of insecticides, applied either as a foliar spray or as a seed treatment, on rates of *C. adspersus* larval parasitism at season's end, despite measurable impacts on numbers of stem weevils in several instances.

Chemical treatments also did not significantly reduce populations of either *D. texanus* or *P. womonana* within planting dates for the study as a whole. Although there were not treatment differences affecting densities of *D. texanus* among the different locations for any of the study years, there were a few instances where treatments did reduce *P. womonana* larval numbers (Tables 2 and 3). Part of the reason could be the generally low densities of both the longhorned beetle and root moth that occurred during the study. The importance of managing *P. womonana* populations in sunflower stalks is uncertain at this time, because the economic impact is not known. However, in locations and years where *P. womonana* densities were greater, chemical treatments significantly reduced densities compared with the controls. The abundance of *D. texanus* has been increasing throughout the sunflower production region and its economic significance is further heightened by its potential for impact on soybean, *Glycine max* (L.) Merr. Yield losses are associated with the lodging of plants girdled by late instars as they prepare for overwintering (Charlet and Glogoza 2004, Michaud and Grant 2005, Niide et al. 2006).

Treatments applied at one plant growth stage compared with degree-days also did not show efficacy in reducing populations of the three pest species in the 2-yr trial at Colby compared with the untreated sunflowers (Tables 5–7). However, in 2002 both treatment timings effectively lowered densities of both sunflower stem weevil and *P. womonana;* but, stem densities of *D. texanus* were only reduced in the late planting date. Although not consistent in all years, chemical control of stem-infesting sunflower pests can be a potentially useful management tactic to lower populations within the sunflower stalk and the timing of treatment is equally effective whether based on the degree-day estimate when 90% of weevils had emerged as adults or plant growth stage.

The guild of stem-infesting insect pests of cultivated central Plains sunflower is a concern to sunflower producers due chiefly to crop losses caused by plant lodging, mainly from the sunflower stem weevil and *D. texanus* (Armstrong et al. 2004, Charlet and Glogoza

2004, Charlet and Aiken 2005). High densities of the latter pest also can result in crop losses to soybean, especially when harvesting is delayed for any reason (Michaud and Grant 2005, Niide et al. 2006). Effective insect management strategies for pests of the sunflower stem are critical to sustained sunflower production in this region. The results from this 3-yr study revealed that chemical control was often reliable in protecting the sunflower crop from stem pests and was relatively insensitive to application timing. Although results in some cases were mixed, overall, there is evidence that growers can use delayed planting as a reliable and effective management tool for reducing stem-infesting pest densities in sunflower stalks in the central Plains. In addition, in the case of the sunflower stem weevil, both chemical control and planting date are compatible with the natural mortality contributed by eight species of larval parasitoids.

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