Systemic Insecticide Injections for Control of Cone and Seed Insects in Loblolly Pine Seed Orchards—2 Year Results

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ABSTRACT: *Three systemic insecticide treatments, emamectin benzoate alone, imidacloprid alone, and a combination of emamectin benzoate and thiamethoxam, were injected one or two times into loblolly pine,* Pinus taeda *L., during a 2 yr period in a seed orchard in east Texas. Single injections of treatments containing emamectin benzoate reduced coneworm (*Dioryctria *spp.) damage by 94–97% during the study period. A second injection after 1 yr did not improve protection. Imidacloprid also significantly reduced coneworm damage in 1999, but not in 2000. Significant reductions in damage from pine seed bugs (*Tetyra bipunctata *Say and* Leptoglossus corculus *Herrich-Schaffer) and an increase in the number of full seeds per cone resulted from imidacloprid and thiamethoxam treatments and to a lesser extent from emamectin benzoate. Yearly injections of imidacloprid or thiamethoxam were required to maintain protection against seed bugs. The best overall treatment, two injections of emamectin benzoate plus thiamethoxam, reduced cone and seed losses from insects by 86%. South. J. Appl. For. 26(3):146–152.*

Key Words: Tree injection, coneworm, seed bug, loblolly pine seed orchard.

Cone and seed insects severely reduce potential seed yields in southern pine seed orchards that produce genetically improved seed for regeneration programs. Two of the most important insect pest groups include the coneworms (*Dioryctria* spp.) that attack flowers, cones and stems of pines and the seed bugs (leaffooted pine seed bug, *Leptoglossus corculus* [Say] and shieldbacked pine seed bug, *Tetyra bipunctata* [Herrich-Schaffer]), that suck the contents from developing seeds in conelets and cones (Ebel et al. 1980). Without a comprehensive insect-control program, these pests commonly destroy 50% of the potential seed crop, and losses up to 90% are not uncommon (Fatzinger et al. 1980).

The use of insecticides is the only known measure for effectively avoiding heavy losses of cones and seeds to insect pests in southern pine seed orchards. Many insecticides and application techniques have been tested and used operationally in southern pine seed orchards over the past 30+ yr. Azinphosmethyl, BHC, DDT, dicrotophos, malathion, carbofuran, and phorate, among others, have been used with varying success to control cone and seed insects (Yates 1968, Barber 1984).

Currently, certain formulations containing azinphosmethyl (Guthion®), permethrin (Ambush®), esfenvalerate (Asana XL®), bifenthrin (Capture®), and *Bacillus thuringiensis* subsp. *kurstaki* (Foray®) are specifically registered by the United States Environmental Protection Agency (EPA) for the control of coneworms and/or seed bugs in southern pine seed orchards (Nord et al. 1984, Lowe et al. 1994). All are applied as foliar sprays by ground-based mist blowers or by aircraft. However, EPA, as required by the Food Quality Protection Act of 1996, is reassessing all existing tolerances for food crop pesticides. Because the risk assessment procedures are stringent, the tolerances of many insecticides, including those mentioned above, will likely be lowered. It is possible that registrations could be lost for some insecticides and their use in other applications could be restricted. In cases where food crop registrations are withdrawn, the manufactures may decide to discontinue production for those uses in seed orchards as well due to economic constraints.

With the potential loss of currently registered foliar insecticides, there is an obvious need for an effective alternative to control cone and seed insects in southern pine seed orchards. The development of such alternative insecticides was identified as the number one priority in a survey of 36

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state and private seed orchard managers (Hodge et al. 1997). A chemical alternative that provides long-term protection (>1 yr) and could be applied via a closed system to individual trees would be preferred by orchard managers, particularly if it is economical, easily applied, and poses low hazard to the applicator.

The injection or implant of systemic insecticides into drill holes on individual pine trees has been evaluated as an alternative to foliar applications, but with limited success (Merkel 1969, 1970, Merkel and DeBarr 1971, Brown et al. 1979, Roques et al. 1996). In loblolly, *Pinus taeda* L., and slash pines, *P. elliottii* Engelm. var. *elliottii*, the holes drilled into tree trunks for insecticide application quickly fill with oleoresin released by the tree in response to the wounding (D. Grosman, personal observation). The function of the oleoresin is to flood the wound and prevent invasion by insects and pathogens. Similarly, the resin may reduce or prevent the uptake of injected or implanted insecticides. To bypass or overcome the resin response of pines, a pressurized high volume injection system called a Systemic Tree Injection Tube (STIT) was recently developed (Helson et al. 2001). Trials conducted on loblolly pine showed that 50 ml of systemic insecticide in solution can be completely injected into a tree in as little as 4 minutes (D. Grosman, unpublished data). Imidacloprid (Bayer Corporation), emamectin benzoate (Syngenta, Inc.), and thiamethoxam (Syngenta, Inc.) have shown promise as viable control options for cone and seed insects.

Preliminary trials in 1998 indicated that low volume injections (2 ml/10 cm trunk circumference) of emamectin benzoate (Arise® SL) reduced coneworm damage by 59.8% compared to the check trees (D. Grosman, unpublished data). However, emamectin benzoate did not reduce seed bug damage levels compared to the check. In contrast, low volume injections of imidacloprid (Pointer®, ArborSystems L.L.C.), a chloronicotinyl, or thiamethoxam (25WG), an experimental product, had no significant impact on coneworm damage levels, but these chemicals reduce seed bug damage by 63.3% and 55.6%, respectively, compared to the controls. Reported here is an experiment initiated in 1999 to evaluate the efficacy of STIT injections of emamectin benzoate, imidacloprid, or a combination of emamectin benzoate and thiamethoxam in reducing seed crop losses in loblolly pine seed orchards in east Texas. The trial was continued into 2000 to determine the extent and longevity of protection resulting from these high volume systemic insecticide injections.

Material and Methods

The study was conducted at the Texas Forest Service Magnolia Springs Seed Orchard, Jasper Co., Texas, in a block containing drought-hardy loblolly pine established in 1964 and 1973. This orchard section was removed from production in 1995. In early spring 1999, eight ramets from each of ten loblolly clones were selected. The treatments were evaluated using the experimental design protocol described by Gary DeBarr (1978) (i.e., randomized complete block with clones as blocks). The treatments included:

1. 4% emamectin benzoate (Arise® SL) by STIT injector (applied April 1999);
2. 4% emamectin benzoate (Arise® SL) by STIT injector (applied April 1999 and April 2000);
3. 4% emamectin benzoate (Arise® SL) and 5% thiamethoxam (25WG) by STIT injector (applied April 1999);
4. 4% emamectin benzoate (Arise® SL) and 5% thiamethoxam (25WG) by STIT injector (applied April 1999 and April 2000);
5. 5% imidacloprid (Admire® EC) by STIT injector (applied April 1999);
6. 5% imidacloprid (Admire® EC) by STIT injector (applied April 1999 & April 2000);
7. Standards–Imidacloprid (Merit® 75WP) in 1999 and esfenvalerate (Asana XL®) in 2000 applied to foliage 5 times at 0.5 oz / 100 gal (imidacloprid) or 9.6 oz / 100 gal (Asana XL“) at 4 wk intervals beginning in April (i.e., April, May, June, July and August);
8. Check (untreated control).

Each chemical treatment (emamectin benzoate, emamectin benzoate plus thiamethoxam, and imidacloprid) was applied using a pressurized STIT injection system (Helson et al. 2001) to each of 20 ramets in April 1999 (just after a heavy rain). Insecticides were injected into each of ten study trees a second time in April 2000 for Treatments 2, 4, and 6. Study trees assigned to Treatments 1, 3, and 5 received no additional injection in 2000. The volume of insecticide solution applied was based on the diameter of each treatment tree (Table 1).

Approximately one hole (1 cm diameter and 7 cm deep) per 10 cm of tree diameter was drilled horizontal into each treatment tree about 30 cm above the ground. The number of holes was based on the volume of insecticide determined for each tree divided by 50 ml (the capacity of the injector). Upon assembly of the system, one injector stile was hammered into each drill hole. Each injector was filled and pressurized to approximately 3500 gscm (= 50 psi). After each injector had drained, the stile was removed, and the drill hole was plugged with a cork to reduce the chance of fungal invasion.

In 1999, treatment 7 (Merit® 75WP) was applied to foliage each growing season beginning in April using a hydraulic sprayer from a bucket truck at 39 l/tree. The distance between test trees was about 20 m to minimize

Table 1.

Tree diam. (cm)	Treatments 1 and 2	3 and 4	5 and 6
<15	20 ml	40 ml combined	30 ml
16–20	20–40 ml	40–80 ml	30–60 ml
21–25	40–60 ml	80–120 ml	60–90 ml
26–30	60–80 ml	120–160 ml	9–120 ml
>30	+ 20 ml/5 cm diam. increment	+ 40 ml/5 cm diam. increment	+ 30 ml/5 cm diam. increment

the effects of drift. The foliar standard was changed from Merit® 75WP to Asana XL® in 2000 to compare the effects of injected insecticides to a more commonly used foliar treatment (Tom Byram, Texas Forest Service, November 2000 pers. comm.).

Coneworm damage was evaluated by collecting all cones present on one-half of each tree in early October. Cone collections were restricted to the southeast half due to the large tree size and spacing and access to the trees. From the samples, counts were made of cones killed by coneworms in the spring (small dead cones) and the summer (large dead or infested cones), and of other damaged and healthy cones. Seed bug damage was evaluated by randomly selecting a subsample of 10 apparently healthy cones/tree. The seed lots from these cones were radiographed according to procedures reported by DeBarr (1970, 1978) and Bramlett et al. (1977). Seeds were classified as filled, seed bug-damaged, second-year aborted ovules, fungus-damaged, seedworm-damaged, or empty. These data were used to determine seed yield/cone and filled-seed yield/cone to measure the extent of seed bug damage. Coneworm and seed bug damage on treated trees was compared to damage on check (untreated) trees to determine percent reduction in damage. Similarly, treated and untreated trees were compared to determine percent gain in full seeds per cone. Coneworm and seed bug data distributions were found to be nonnormal. Subsequently, the data were transformed using the arcsin $\sqrt{\%}$ or the $\log_{10}(x + 1)$ transformations and analyzed by the GLM procedure. Fisher's Protected LSD test was used to detect significant differences among treatments at the $\propto = 0.05$ probability level (StatView 1999).

Results and Discussion

The STIT injector was successfully used to inject a high volume (50 ml) of insecticide solution into loblolly pines in a short period of time, often less than 4 min. for emamectin benzoate and 10 to 15 min. for imidacloprid and thiamethoxam. None of the treatments appeared to adversely affect the health of the injected trees, i.e., no phytotoxicity or mortality was observed.

The orchard block containing the treatment trees had not been sprayed since 1995, suggesting that pressure from coneworms and seed bugs would be moderate to high. This was confirmed for coneworms by high trap catches in the area [in 1999 *Dioryctria amatella* (Hulst) numbers were at their highest level in over 15 yr] and over 21% damage to check cones in both 1999 and 2000 (Table 2). Other coneworm species known to occur in the orchard included *D. clarioralis* (Walker), *D. disclusa* Heinrich and *D. merkeli* Mutuura & Munroe. High numbers of seed bugs were observed in the trees in 1999. This was confirmed by the 53% damage to seed from check trees (Table 2). Seed bug numbers appeared to decline in 2000 based on field

Table 2. Mean percentages (± SE) of cones killed early and late by coneworms, other-damaged cones, and healthy cones on loblolly pine protected with systemic injection of emamectin benzoate (EB), emamectin benzoate + thiamethoxam (EB + Thia.), imidacloprid (Imid.) or foliar treatments of imidacloprid or Asana XL®, Magnolia Springs Seed Orchard, Magnolia Springs, Jasper Co., TX, 1999–2000.

Year	Treatment	Application technique, treatment date(s)	N	Mean coneworm damage: Early (small dead)		Mean coneworm damage: Late (large dead and infested)		Mean coneworm damage: Total		Mean other damage*		Mean healthy	
				(%)									
1999	EB	STIT - Apr., '99	20	1.0 ± 0.3	a†	0.3 ± 0.1	a	1.3 ± 0.4	a	41.3 ± 4.4	a	57.4 ± 4.5	b
	EB + Thia.	STIT - Apr., '99	20	3.3 ± 0.6	b	0.9 ± 0.2	a	4.2 ± 0.8	b	42.5 ± 3.2	a	53.3 ± 3.2	b
	Imid.	STIT - Apr., '99	20	6.3 ± 0.8	c	5.4 ± 1.3	b	11.8 ± 1.8	c	38.6 ± 2.7	a	49.6 ± 3.8	b
	Imid.	Hydraulic Foliar 5× in '99	10	9.8 ± 1.3	d	8.1 ± 1.7	c	17.9 ± 2.8	d	33.9 ± 3.9	a	48.1 ± 4.7	ab
	Check		10	12.0 ± 1.7	d	9.4 ± 2.8	c	21.4 ± 3.8	d	41.1 ± 2.7	a	37.6 ± 3.8	a
2000	EB	STIT - Apr., '99	10	0.1 ± 0.1	a	0.5 ± 0.3	a	0.6 ± 0.3	a	47.0 ± 7.7	a	52.4 ± 7.8	a
	EB	STIT - Apr., '99 & '00	10	0.4 + 0.3	a	0.1 ± 0.1	a	0.5 ± 0.3	a	60.1 ± 5.9	a	39.4 ± 5.9	a
	EB + Thia.	STIT - Apr., '99	10	0.2 ± 0.1	a	0.5 ± 0.4	a	0.7 ± 0.5	a	51.6 ± 6.1	a	47.8 ± 6.2	a
	EB + Thia.	STIT - Apr., '99 & '00	10	0.5 ± 0.3	a	0.4 ± 0.2	a	0.8 ± 0.3	a	55.1 ± 7.2	a	44.6 ± 7.3	a
	Imid.	STIT - Apr., '99	10	3.4 ± 1.1	b	17.7 ± 4.2	b	21.1 ± 5.0	b	44.8 ± 6.4	a	34.1 ± 6.9	a
	Imid.	STIT - Apr., '99 & '00	10	4.3 ± 1.3	b	12.1 ± 4.4	b	16.4 ± 4.3	b	44.2 ± 4.9	a	39.3 ± 6.0	a
	Asana XL	Hydraulic Foliar 5× in '00	10	5.0 ± 1.1	b	7.4 ± 2.2	b	12.4 ± 2.9	b	43.5 ± 5.5	a	44.1 ± 7.0	a
	Check		10	4.0 ± 0.9	b	17.1 ± 4.2	b	21.1 ± 4.3	b	51.3 ± 3.6	a	27.6 ± 5.0	a

* Mortality or wounds caused by drought, pitch canker, squirrel, midge, or mechanical damage.

† Means followed by the same letter in each column of the same year are not significantly different at the 5% level based on Fisher's Protected LSD.

observations and lower levels of damage (24%) to seed from check trees compared to 1999. Seedworm (*Cydia* spp.) damage to seed from check trees was considered insignificant, 1% or less in 1999 and 2000, so the data were not included in the analysis.

Coneworm Damage

In 1999, coneworm damage levels on check trees were similar early in the growing season compared to late in the season (Table 2). However, damage on emamectin benzoate-treated trees was generally threefold higher early compared to later in the season. This suggests that complete translocation of the chemical into the tree canopy requires two or more months. Treatments that included emamectin benzoate consistently provided the best overall protection against coneworm attack (Table 2). Overall coneworm damage reductions for emamectin benzoate alone, emamectin benzoate + thiamethoxam, and imidacloprid, were 94.1%, 80.6%, and 63.9%, respectively, compared to the check (Figure 1). The imidacloprid foliar treatment was ineffective against coneworms (Table 2). "Other" damage/mortality was exceptionally high, but consistent across all treatments (range: 35%—46%) (Table 2). Although not quantified, most of the damage/mortality is believed to be drought induced. The percent of cones classified as healthy was significantly higher for the three injection treatments compared to the check (Table 2).

In 2000, only those treatments containing emamectin benzoate (alone or combined with thiamethoxam) significantly reduced early and late coneworm damage compared to the check (Table 2). Overall reductions for both emamectin benzoate alone and emamectin benzoate plus thiamethoxam treatments ranged from 96.2% to 97.6% compared to the check (Figure 1). This indicates that the addition of thiamethoxam did not improve or reduce the performance of emamectin benzoate against coneworms. Two-injection treatments containing emamectin benzoate did not differ significantly from single-injection treatments. Therefore, a single injection of emamectin benzoate was sufficient to protect trees against coneworms for at least two full years. As in 1999, severe drought conditions during the summer of 2000 appeared to have caused exceptionally high second-year cone abortion (classified as other damage). The level of other damage/mortality was more variable (range: 44—60%) across treatments in 2000 and appears to have had a confounding effect on the percent of healthy cones remaining (Table 2).

Seed Bug Damage

In 1999, seed bug damage levels in check cones were exceptionally high (53%, Table 3); four times greater than observed in 1998 (13%). Levels of early season damage (seed bug-aborted) were markedly lower compared to late season (seed bug-damaged) damage. Seed bug-aborted seeds are caused by the leaffooted pine seed bugs feeding on developing seeds in cones during late May through June. In contrast, seed bug-damaged seeds, detectable on the radiographs, are caused by leaffooted and shieldbacked pine seed bugs feeding on maturing seeds in August and early September. This suggests that shieldbacked pine seed bugs caused the majority of the damage in 1999. All treatments provided significant protection against seed bug attack, and most, with the exception of emamectin benzoate alone, improved the yield of full seeds (Table 3). Overall seed bug damage reductions for imidacloprid, emamectin benzoate + thiamethoxam, imidacloprid foliar, and emamectin benzoate alone were 81.9%, 52.9%, 45.3%, and 33.7%, respectively, compared to the check (Figure 2). The same treatments improved full seed yield by 225.1%, 159.8%, 89.6%, and 72.1%, respectively, compared to the check (Figure 3). The number of seeds per

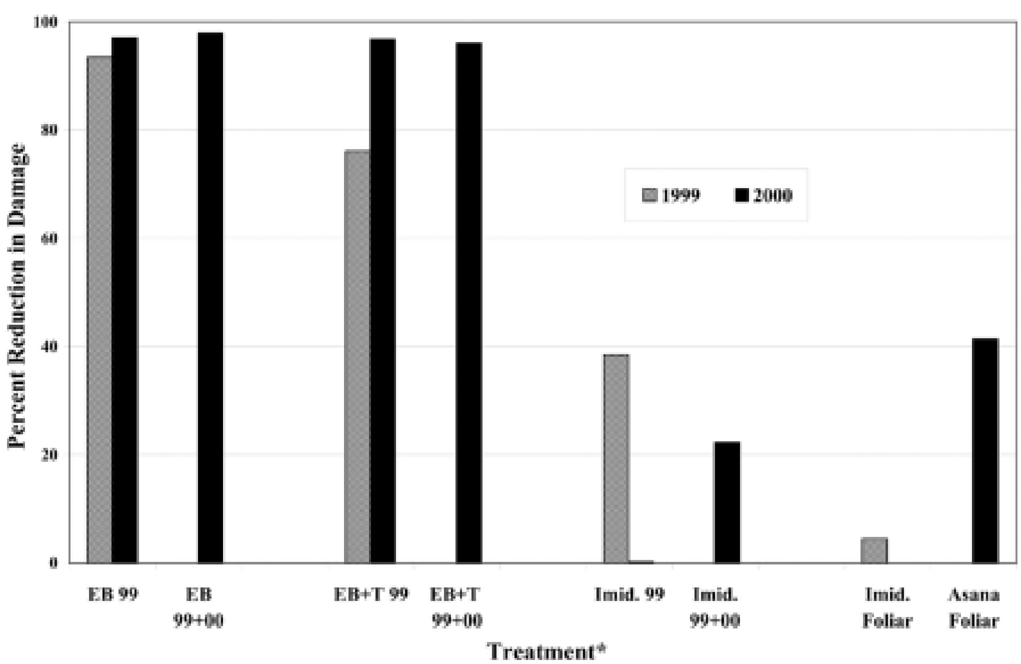

Figure 1. Percent reduction in coneworm (*Dioryctria* spp.) damage in 1999 and 2000 compared to control loblolly pine trees, Magnolia Springs Seed Orchard, Jasper Co., Texas. [The treatments indicate the product injected (EB = emamectin benzoate; EB + T = emamectin benzoate + thiamethoxam; Imid. = imidacloprid) and the timing of injections (99 = 1999 only; 99 + 00 = 1999 and 2000).]

Table 3. Seed bug damage, seed extracted, and seed quality (Mean ± SE) from second-year cones of loblolly pine protected with systemic injection of emamectin benzoate (EB), emamectin benzoate + thiamethoxam (EB + Thia.), imidacloprid (Imid.) or foliar treatments of imidacloprid or Asana XL®, Magnolia Springs Seed Orchard, Magnolia Springs, Jasper Co., TX, 1999–2000.

Year	Treatment	Application technique, treatment date(s)	*N*	Mean seed bug damage (%): Early (2nd yr abort)	Late	Total	Mean no. seeds per cone	Mean no. filled seed per cone	Mean no. empty seed per cone
				(%)					
1999	EB	STIT - Apr., '99	20	0.7 ± 0.2 b*	34.4 ± 3.7 c	35.1 ± 3.8 c	66.4 ± 7.0 a	32.1 ± 6.5 ab	13.3 ± 2.4 a
	EB + Thia.	STIT - Apr., '99	20	0.4 ± 0.1 ab	24.6 ± 3.9 b	25.0 ± 3.9 b	83.1 ± 6.9 a	48.4 ± 6.2 c	16.1 ± 1.8 a
	Imid.	STIT - Apr., '99	20	0.4 ± 0.2 a	9.2 ± 1.2 a	9.6 ± 1.3 a	78.7 ± 6.5 a	60.5 ± 5.8 c	10.6 ± 1.2 a
	Imid.	Hydraulic Foliar 5× in '99	10	0.9 ± 0.3 b	28.1 ± 2.2 bc	29.0 ± 2.2 bc	68.1 ± 7.0 a	35.3 ± 4.5 bc	12.0 ± 2.2 a
	Check		10	1.7 ± 0.3 c	51.3 ± 5.3 d	53.0 ± 5.5 d	60.2 ± 6.9 a	18.6 ± 5.8 a	10.5 ± 1.6 a
2000	EB	STIT - Apr., '99	10	0.5 ± 0.3 a	15.6 ± 2.8 b	16.1 ± 3.0 b	81.3 ± 11.5 a	59.1 ± 9.6 ab	7.6 ± 1.1 a
	EB	STIT - Apr., '99 & '00	10	0.6 ± 0.2 ab	14.4 ± 2.0 b	15.1 ± 2.1 b	89.0 ± 9.1 a	62.6 ± 7.5 abc	10.2 ± 1.6 a
	EB + Thia.	STIT - Apr., '99	10	0.4 ± 0.1 a	17.2 ± 2.8 bc	17.6 ± 2.9 bc	97.6 ± 7.2 a	66.1 ± 6.0 bcd	12.2 ± 2.3 a
	EB + Thia.	STIT - Apr., '99 & '00	10	0.7 ± 0.3 ab	6.9 ± 1.4 a	7.6 ± 1.5 a	103.8 ± 6.9 a	86.8 ± 7.4 d	8.7 ± 1.1 a
	Imid.	STIT - Apr., '99	10	0.5 ± 0.2 a	14.4 ± 3.1 b	14.9 ± 3.2 b	96.5 ± 9.9 a	68.9 ± 9.2 bcd	12.3 ± 2.1 a
	Imid.	STIT - Apr., '99 & '00	10	0.2 ± 0.1 a	5.5 ± 1.5 a	6.1 ± 1.5 a	105.6 ± 10.3 a	86.1 ± 8.5 cd	11.1 ± 1.9 a
	Asana XL	Hydraulic Foliar 5× in '00	10	0.3 ± 0.2 a	5.2 ± 0.8 a	5.5 ± 0.8 a	93.3 ± 5.5 a	75.1 ± 5.1 bcd	10.4 ± 1.1 a
	Check		10	1.3 ± 0.5 b	23.0 ± 3.2 c	24.3 ± 3.5 c	75.8 ± 10.3 a	48.3 ± 6.9 a	8.8 + 2.3 a

cone and empty seeds per cone did not differ among treatments—indicating that these characters are not influenced by seed bug feeding (Table 3).

In 2000, seed bug damage levels in check cones (24%) were less than half 1999 levels (Table 3). The higher level of damage late in the growing season compared to earlier in the

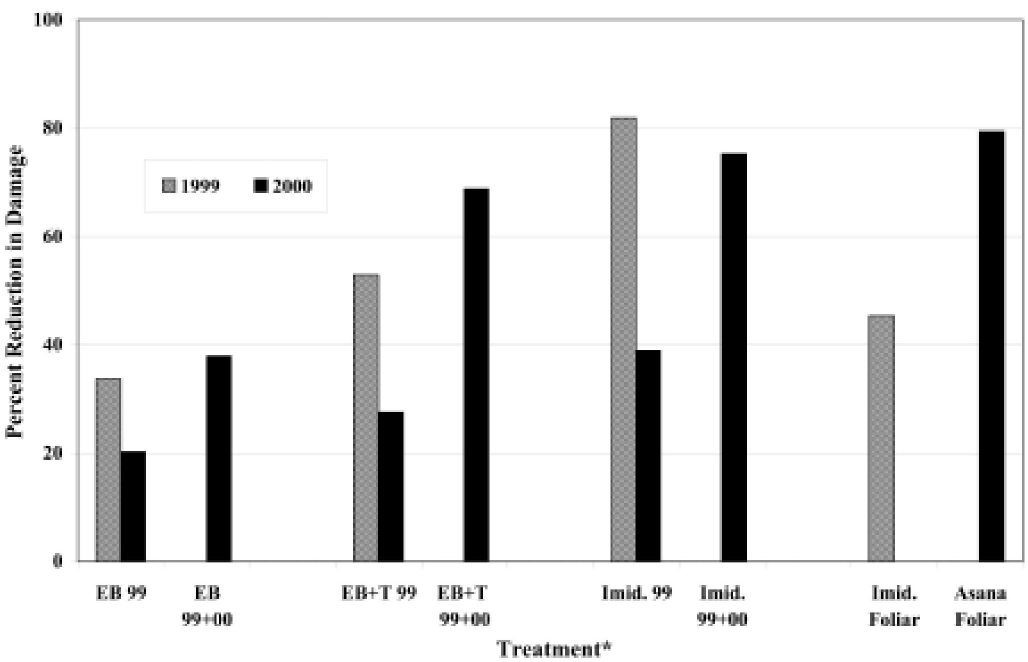

Figure 2. Percent reduction in seed bug (*Tetyra bipunctata* and *Leptoglossus corculus*) damage in 1999 and 2000 compared to control loblolly pine trees, Magnolia Springs Seed Orchard, Jasper Co., Texas. [The treatments indicate the product injected (EB = emamectin benzoate; EB + T = emamectin benzoate + thiamethoxam; Imid. = imidacloprid) and the timing of injections (99 = 1999 only; 99 + 00 = 1999 and 2000).]

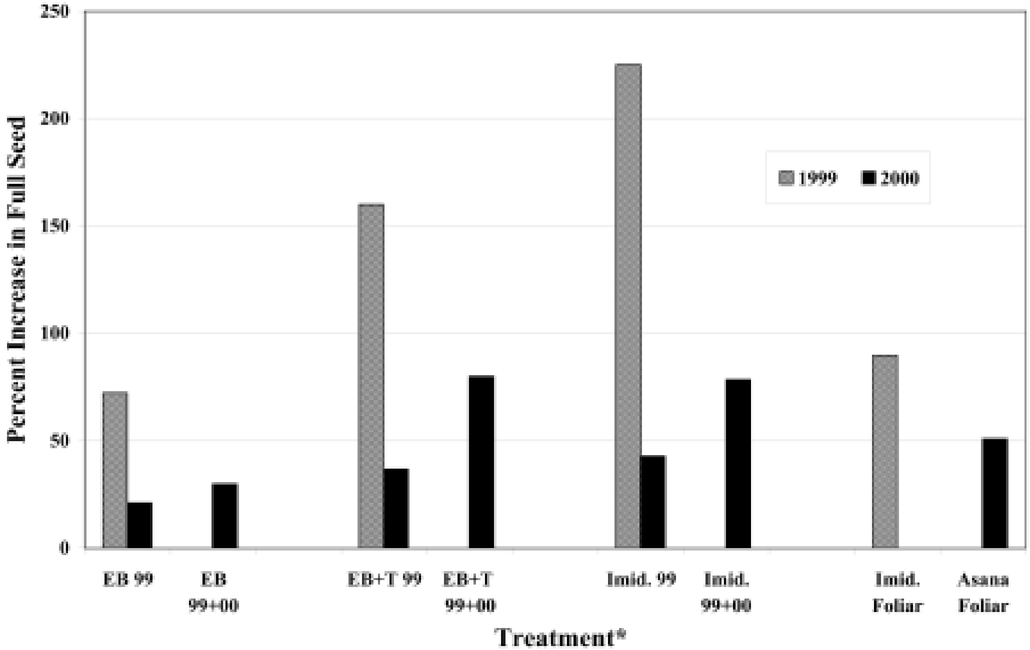

Figure 3. Percent gain in full seed per cone in 1999 and 2000 compared to control loblolly pine trees, Magnolia Springs Seed Orchard, Jasper Co., Texas. [The treatments indicate the product injected (EB = emamectin benzoate; EB + T = emamectin benzoate + thiamethoxam; Imid. = imidacloprid) and the timing of injections (99 = 1999 only; 99 + 00 = 1999 and 2000).]

year again indicates that the shieldbacked pine seed bug has a much greater impact on seed production at this orchard than did the leaffooted pine seed bug. Most treatments (injection and foliar) significantly reduced early and late seed bug damage and increased the number of full seeds per cone compared to the check. Single injections of most chemicals from 1999 continued to provide significant protection against seed bugs through the 2000 growing season. However, additional reductions in damage were obtained with a second injection of treatments containing thiamethoxam or imidacloprid. This indicates that yearly treatments of thiamethoxam or imidacloprid are generally necessary to maintain adequate protection against seed bugs. Overall reductions for the Asana XL® foliar and two injection treatments of emamectin benzoate plus thiamethoxam, imidacloprid, and emamectin benzoate alone were 79.4%, 75.2%, 68.8%, and 37.9%, respectively, compared to the check (Figure 2). The same treatments improved full seed yield by 50.8%, 79.9%, 78.3%, and 29.7%, respectively, compared to the check (Figure 3). The number of seeds per cone and empty seeds per cone did not differ among treatments (Table 3).

Overall Insect Damage

An estimate of the combined losses due to two primary insect pest groups, coneworms and seed bugs, can be calculated by adding the proportion of coneworm-damaged cones to the proportion of all seed in healthy cones damaged by seed-bug. (Note: this does not take into account the portion of sound seed that might be retrieved from some of the less damaged "other" cones.) In this study, it is conservatively estimated that coneworms and seed bugs in combination reduced the potential seed crops of check trees by 41.1% in 1999 and 28.4% in 2000 (Table 4). Two treatments stand out with regard to their ability to reduce overall insect damage: emamectin benzoate alone and emamectin benzoate + thiamethoxam. A second injection of these treatments in 2000 reduced overall insect damage by 79.0% and 85.7%, respectively. It is unknown why a second injection of imidacloprid failed to provide the same level of protection as it did in 1999.

Conclusions

The STIT injector was successfully used to inject high volumes of insecticide solutions into loblolly pine. Over the past 2 yr, emamectin benzoate has exhibited the best overall protection against coneworms, but was less effective against seed bugs. The data suggest that a single injection of emamectin benzoate can protect trees against coneworms for 18 months or longer. A second injection is not necessary during the second growing season. However, it appears the effects of treatments on coneworms were delayed early in 1999. This suggests that it may be preferable to inject in the fall to obtain complete protection the following year. The Arise® SL formulation of emamectin benzoate is reported to be highly effective (providing 4+ yr of protection) in Japan against the pinewood nematode, *Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle, and its cerambycid vector, *Monochamus alternatus* Hope (David Cox, Syngenta, October 1997 pers. comm.). The extent of this chemical's residual activity against cone and seed insects has yet to be determined.

In contrast, imidacloprid and thiamethoxam provided good protection against seed bugs in 1999, but generally showed little or inconsistent effects against coneworms. Imidacloprid and thiamethoxam also provided extended protection (18 months), but not as extensive as was found for emamectin benzoate. Protection improved significantly with

Table 4. Mean % (± SE) cone and seed losses from insects (coneworms and seed bugs) and reductions in damage from second-year cones of loblolly pine protected with systemic injection of emamectin benzoate (EB), emamectin benzoate + thiamethoxam (EB + Thia.), imidacloprid (Imid.) or foliar treatments of imidacloprid or Asana XL, Magnolia Springs Seed Orchard, Magnolia Springs, Jasper Co., TX, 1999 - 2000.

			1999		2000	
Treatment	Application technique, treatment date(s)	N	Mean combined losses	Mean reduction	Mean combined losses	Mean reduction
			(%)			
EB	STIT - Apr., '99	20	20.1 ± 2.4 a*	51.0		
EB	STIT - Apr., '99	10			9.2 ± 2.4 ab	67.5
EB	STIT - Apr., '99 & '00	10			6.0 ± 1.2 a	79.0
EB + Thia.	STIT - Apr., '99	20	17.4 ± 2.2 a	57.7		
EB + Thia.	STIT - Apr., '99	10			8.0 ± 0.8 ab	71.9
EB + Thia.	STIT - Apr., '99 & '00	10			4.1 ± 0.7 a	85.7
Imid.	STIT - Apr., '99	20	15.9 ± 1.7 a	61.2		
Imid.	STIT - Apr., '99	10			25.6 ± 4.8 de	9.7
Imid.	STIT - Apr., '99 & '00	10			18.9 ± 4.2 cd	33.4
Imid.	Hydraulic Foliar 5× in '99	10	31.6 ± 2.7 b	23.1		
Asana XL	Hydraulic Foliar 5× in '00	10			14.8 ± 2.7 bc	47.7
Check		10	41.1 ± 3.6 b		28.4 ± 3.0 e	

* Means followed by the same letter in each column of the same year are not significantly different at the 5% level based on Fisher's Protected LSD.

a second injection of either chemical. Given the extended protection provided by emamectin benzoate (coneworms) and imidacloprid (seed bugs) into 2000, further evaluation of the residual effects of 1999 and 2000 treatments are warranted into 2001. Additional studies are planned to determine optimal application rates and timing.

Individual tree injections in seed orchards offer several advantages. Control efforts can be allocated to clones on the basis of inherent susceptibility to insect attacks, genetic worth, and high potential for seed production, as suggested by DeBarr (1971). With these criteria, only 10–25% of the ramets in an orchard might need to be protected with insecticides. In turn, the pesticide load (amount of pesticide per acre) produced by conventional application techniques could be substantially reduced. Potential environmental concerns from insecticides in runoff water could be virtually eliminated because insecticides would be contained in the tree. Specific situations where systemic injections may be particularly useful include protecting seeds on trees with control pollinated crosses, protecting selected ramets of genetically valued clones in early-generation orchards after emphasis shifts to newer orchards, and providing insect control in orchards located in environmentally sensitive sites where conventional air and ground sprays may be hazardous.

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