FOREST ENTOMOLOGY

Use of Systemic Fipronil and Imidacloprid to Control Regeneration Pests of Loblolly Pine

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J. Econ. Entomol. 104(4): 1272–1279 (2011); DOI: 10.1603/EC10446

ABSTRACT Regeneration pests of loblolly pine (*Pinus taeda* L.) threaten growth and survival in intensively managed loblolly pine plantations throughout the southeastern United States. The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), in particular, often reduces growth of loblolly pine but has been difficult to control with traditional insecticides due to multiple annual generations and multi-year infestations which are difficult to predict in timing and location. Relatively new systemic insecticide products offer a solution in that their efficacy persists through multiple generations and years after a single application. Efficacy of systemic imidacloprid and fipronil were evaluated side by side across multiple sites in Virginia. Significant reductions in Nantucket pine tip moth damage were noted in trees treated with either the imidacloprid or fipronil product compared with check trees. After 2 yr, growth improvement of treated trees relative to controls was modest and not significant at all sites, but per acre volume indices were significantly greater in treated blocks as a result of higher tree survival. Reduced seedling mortality was attributed primarily to prevention of damage by pales weevil, *Hylobius pales* Herbst (Coleoptera: Curculionidae), by both insecticide treatments. Control of pales weevil in addition to pine tip moth suggests that systemic insecticide products with a long window of efficacy might control additional nontargeted pests.

KEY WORDS Nantucket pine tip moth, pales weevil, systemic insecticides, fipronil, imidacloprid

Loblolly pine (*Pinus taeda* L.) covers ≈16 million ha of forestland in the southeastern United States, more than half of which consists of plantations (South and Buckner 2003). Although tree growth rates in intensively managed pine plantations continue to increase across industrial lands and on some nonindustrial private forest land (Borders and Bailey 2001), control of a variety of common pests is sometimes necessary to maintain plantation health along with reasonable growth rates and profit margins. Over the past few decades, loblolly pine silviculture has included many standard, cost-effective practices to manage many of the most common pest problems in highly managed plantations in the southeastern United States. These include 1) suppressing weed competition via appropriate site preparation and the judicious use of pre- and postemergent herbicides (Miller et al. 1991, Fox et al. 2007); 2) use of genetically improved seedlings, including those that contain genetic resistance to fusiform rust [*Cronartium quercuum* (Berk.) Miyabe ex. f. sp. *fusiforme*] (Bridgewater et al. 2005); 3) treatment of seedlings in the nursery with pyrethroid insecticides to prevent damage and mortality due to regeneration weevils, pales weevil [*Hylobius pales* (Herbst) (Coleoptera: Curculionidae)] and pitch-eating weevil [*Pachylobius picivorus* (Germar) (Grosman 1998)]; and 4) thinnings to prevent or limit damage from bark beetles such as the southern pine beetle (*Dendroctonus frontalis* L.) (Coleoptera: Curculionidae), pine engraver beetles (*Ips* spp.) (Coleoptera: Curculionidae) and black turpentine beetle (*Dendroctonus terebrans* L.) (Coleoptera: Curculionidae) (Nowak et al. 2008).

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), although not typically a lethal pest, nonetheless negatively impacts the early growth of southern pines more than any other insect, particularly in intensively managed plantations where infestations are often quite severe (Lashomb et al. 1978, Cade and Hedden 1987, Berisford et al. 1989, Nowak and Berisford 2000, Asaro et al. 2003). Therefore, it is likely that widespread economic losses due to delayed growth and extended rotation times have occurred over many decades, although this has been difficult to quantify due to a lack of data (Asaro et al. 2003).

Nantucket pine tip moth is ubiquitous throughout the southern pine-growing regions of the southeast from Virginia south to northern Florida and west to Texas (Berisford, 1988; Asaro et al. 2003). Adult tip moths oviposit on needles and shoots of the host tree. Upon hatching, first instars mine needles, whereas second instars feed at needle or bud axils, forming a characteristic silk tent covered with resin. Subsequent instars (three–five) feed inside buds and shoots, where pupation ultimately occurs. Pupae are the overwintering stage of this insect (Berisford 1988). Three tip moth generations oc-

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cur in the Piedmont and Coastal Plain of Virginia. Adult emergence of the overwintering generation normally occurs from mid-March to mid-April. First and second generation adults generally emerge during June and August, respectively.

Historically, chemical control of tip moth infestations has not been widely practiced except in high value plantings such as Christmas tree plantations, seed orchards, and progeny tests. Although many in forest industry have acknowledged the negative impact of this pest on tree growth (Cade and Hedden 1987, Cameron 1996), past use of pyrethroid insecticides to control pine tip moths in plantations has been limited due to the need for spray-timing models and complex spray schedules. Spray-timing models require accumulation of degree-days until a given bio-fix point is reached that would indicate an optimal spray date for each tip moth generation (Fettig et al. 2000a). In addition, spraying each of these generations, which can number from two to five throughout the range of *R. frustrana* and require spray schedules over multiple years (Fettig et al. 2000a, 2000b; Asaro et al. 2003) is impractical, despite the fact that attempts have been made to determine an optimal spray schedule for multiple generations and years in which not every generation needs to be controlled (Fettig et al. 2000b). Even so, the fact that *R. frustrana* can seriously impact early tree growth over multiple years in plantations with decades-long rotation times has confounded clear cost–benefit analyses on chemical control measures, calling into question the need for such practices. Forest industry, therefore, has not readily adopted chemical control measures for pine tip moths (Cameron, 1996; Asaro et al. 2006). An additional complication is that although insecticide sprays are most effective during spring and early summer, tip moth becomes more difficult to control during the later generations in late summer and fall due to asynchronous development of life stages (Fettig and Berisford 1999; Fettig et al. 1998, 2000a; Asaro et al. 2003). There are also many locations throughout the South where generations overlap considerably, even during the spring generation, which confounds accurate spray-timing (McCravy et al. 2004).

One potential solution to these multiple problems may be the use of systemic insecticides, particularly if control from a single application can carry over multiple tip moth generations and years. Systemic insecticides are absorbed by the tree's root system and circulated throughout the rest of the plant. Two systemic insecticide products were tested in this study, both of which became available only recently. SilvaShield Forestry Tablets (Bayer Environmental Science), registered by the Environmental Protection Agency (EPA) in 2006, is a 20% imidacloprid product formulated as a tablet with a small amount of fertilizer incorporated and designed to be placed directly into the planting hole during tree planting operations, or adjacent to the seedling if applied after planting. It is registered for use in plantation forestry and recommended for control of cottonwood leaf beetle (*Chrysomela scripta* F.) (Coleoptera: Chrysomelidae) and aphids (Heteroptera: Aphididae) in hybrid poplar (*Populus* spp.) as well as Nantucket pine tip moth, aphids, and soft scales (Heteroptera: Coccidae) in pines. PTM Insecticide (BASF), registered by EPA in 2007, contains 9.1% fipronil in a liquid formulation that is mixed with water and applied into the planting hole or ≈7.5 cm below ground into the rooting zone of each planted tree after planting. Typically this is done with a small, light weight spot gun that has a 70-cm stainless steel spear with tiny openings on the end through which product is released once the soil is penetrated. PTM is registered to control Nantucket pine tip moth and pine bark aphids (*Cinara* spp.).

Based on the product labels and subsequent reports on efficacy (Grosman 2010), our test hypothesis was that both of these products, when applied during or immediately after planting, would significantly limit damage by each successive Nantucket pine tip moth generation over a 2-yr period. To our knowledge, this is the first published study that tests both of these products for their efficacy against the Nantucket pine tip moth.

Materials and Methods

During March 2008, study plots were installed in seven recently hand-planted loblolly pine plantations in the piedmont and coastal plain of Virginia (Table 1). Four sites (Burke, Clay, McIvor, McKinney) owned by MeadWestvaco Corporation were intensively managed stands that received some form of site preparation (chemical, mechanical, or burn). Two of these four also received additional chemical treatments for herbaceous weed control, woody weed control, or both after planting. The other three sites received no chemical site preparation to control weeds. The James City site was owned by a private landowner and received an application of woody weed control after planting. Another site, owned by Paul D Camp Community College (PDCCC) in Franklin, VA, received mechanical site preparation only. The final site, on the Appomattox-Buckingham State Forest (ABSF), owned and managed by the Virginia Department of Forestry, received a site-prep burn only. These parameters present a broad range of conditions under which loblolly pine is grown in Virginia.

At each site, four replications of 25-tree row plots were installed as randomized complete blocks representing two or three treatments: an untreated check (all sites), PTM (at all sites) and SilvaShield (SS) (at five of seven sites). For the PTM treatments, insecticide dilution was applied to the root zone of each tree within one week of planting using a PTM Applicator Probe (Enviroquip, Monroe, NC). For the SS treatment, tablets were dropped into the planting hole of each tree manually during planting. Shortly after planting, height and ground-line diameter were measured on all trees in the study.

Damage from Nantucket pine tip moth was assessed after each of three larval generations during June, August, and October of 2008 and 2009. The total number of infested and uninfested tips was counted in the top whorl of each tree to estimate percentage of infested shoots.

Table 1. Site locations and stand characteristics

	ABSF	Burke	Clay	James City	McIvor	McKinney	PDCCC
Latitude	37° 24′ 38.4″N	37° 16′ 36.5″N	37° 08′ 46.2″N	37° 21′ 25.9″N	37° 09′ 48.8″N	37° 27′ 41.9″N	36° 40′ 35.2″N
Longitude	78° 37′ 37.4″W	78° 51′ 53.5″W	78° 54′ 37.9″W	76° 51′ 38.4″W	78° 57′ 10.0″W	78° 41′ 40.2″W	78° 55′ 59.5″W
County	Buckingham	Campbell	Campbell	James City	Campbell	Appomattox	City of Franklin
Province	Piedmont	Piedmont	Piedmont	Coastal Plain	Piedmont	Piedmont	Coastal Plain
Prior stand type	Virginia pine	Loblolly pine	Loblolly pine	Mixed loblolly (30%) and hardwood (70%)	Loblolly pine	Loblolly pine	Loblolly pine
Harvest completion date	June 2007	17 March 2007	4 Oct. 2007	Spring 2005	12 Jan. 2007	20 April 2007	12 June 2007
Site prep method and date	Burn July 2007	Burn 23 May 2007	Mechanical 23 Jan. 2008	None	Mechanical 23 Feb. 2007 Chemical 16 Sept. 2007 48 oz. Imazapyr 1 oz. Escort 32 oz. surfactant	Chemical 24 Sept. 2007 48 oz. Rotary 2SL 1 oz. MSM DF 32 oz. Summit 910	Mechanical
Planting date	March 2008	26 March 2008	26 March 2008	Spring, 2008	26 March 2008	16 March 2008	27 March 2008
Planting density (trees per acre)	500	542	523	454	498	458	435
Herbaceous weed control (date and rate)	None	40 oz. Imazapyr 3 oz. surfactant 9 April 2008	40 oz. Imazapyr 3 oz. surfactant 9 April 2008	None	None	None	None
Woody weed control (release date and rate)	None	8 oz. Imazapyr 1 oz. Escort 8 oz. surfactant 12 Aug. 2008	8 oz. Imazapyr 1 oz. Escort 8 oz. surfactant 24 Aug. 2009	5 Oct. 2008 12 oz. Arsenal	None	None	None
Insecticide treatments applied	14 March 2008	26 March 2008	26 March 2008	12 March 2008	26 March 2008	12 March 2008 (PTM and SS in hole) 1 April 2008 (SS adjacent)	13 March 2008

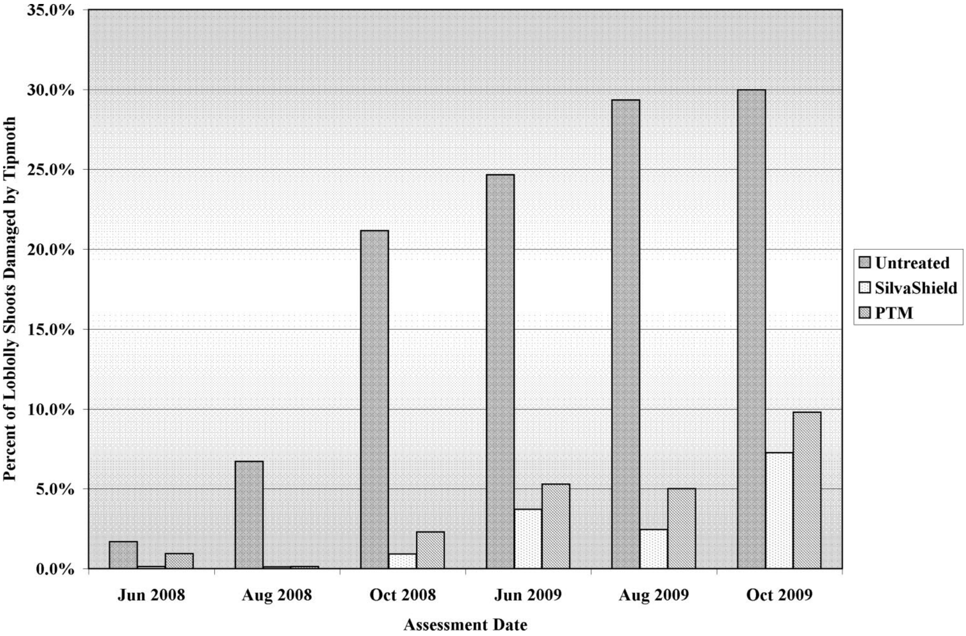

Fig. 1. Average percentage of loblolly pine shoots damaged by Nantucket pine tip moth across all sites and sample dates. Note: error bars are lacking because statistics analyzed treatment differences within individual sites rather than across sites.

Fettig and Berisford (1999) reported strong correlations between top whorl and whole-tree damage estimates among pine trees aged 2–5 yr and concluded that top-whorl damage estimates were the best compromise between accuracy and labor. Although the study was intended to focus on damage from Nantucket pine tip moth, damage from other insect pests as well as seedling mortality were noted throughout. At some sites (Clay, McIvor, and James City), seedling mortality was determined to be caused primarily by heavy feeding of regeneration weevils, as indicated by characteristic debarking, pock-marked appearance and resin-filled holes in the bark on the stems of dead seedlings. Both pales and pitch-eating weevils are known to occur in the study area and cause similar damage, but pales weevil is much more common (Nord et al. 1982) and are denoted exclusively hereafter.

In plantation forestry, pine seedlings used on sites determined to be high hazard for pales weevil damage are routinely treated with permethrin in the nursery before lifting. However, because these nursery treatments can also potentially prevent tip moth damage during the spring of the first year, untreated seedlings were used in the study plots to avoid confounding affects with the systemic insecticide treatments. The incidence of pales weevil attack on some of the study plots turned out to be fortuitous in that it allowed us to evaluate efficacy of SS and PTM insecticides on this pest as well. Note, however, that pales weevil control is not suggested by either insecticide label. All plantation trees outside each of the study plots were treated for pales weevil with a standard permethrin spray applied over the nursery bed.

During November and December 2009, after 2-yr of growth, tree height and ground-line diameter were measured. A per acre volume index was calculated for each plot as the average volume per tree (pi × r^2 × h, with h being tree height and r being one-half tree diameter) times the number of trees per acre at each site times average survival per plot. All damage and survival data were arcsine square root transformed, and along with growth data, were analyzed using analysis of variance (ANOVA) on blocks. When necessary, multiple comparison tests among treatments were performed on plot means within each site and sample date for damage, percentage of survival and growth using the Holm–Sidak multiple comparison test (SigmaStat version 3.1, Systat Software, Inc., San Jose, CA).

Results and Discussion

The SS (imidacloprid) and PTM (fipronil) treatments both prevented tip moth damage to loblolly pine through the first two growing seasons after planting, and both improved survival on some sites (Figs. 1 and 2). Individual tree growth response was not significant on most sites and was modest where a response occurred, but combined with the improved survival the treatments led to an average volume per acre gain of ≈69%.

Three of the sites (PDCCC, ABSF, and Clay) experienced little or no tip moth activity the first year, but all seven locations had significant damage during most of the second year, averaging 25–30% of shoots on the check (untreated) plots (Table 2). Although these damage levels were not very severe in terms of their potential growth impact to trees, they were high enough to show a significant insecticide treatment affect. Both insecticides continued to provide tip moth protection through the second year, although there was evidence that the

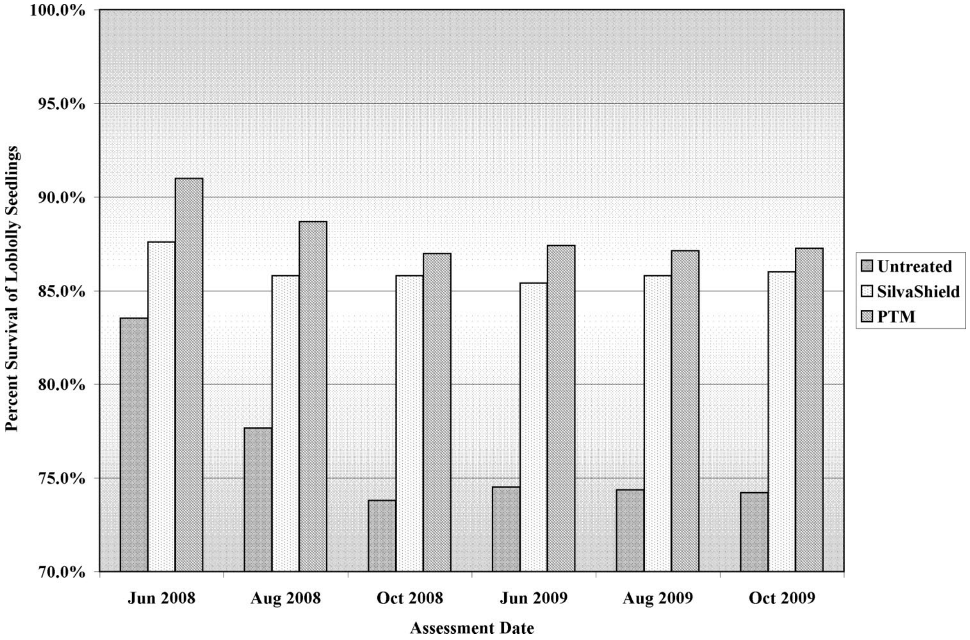

Fig. 2. Average percentage of survival of loblolly pine seedlings across all sites and sample dates. Note: error bars are lacking because statistics analyzed treatment differences within individual sites rather than across sites.

protection was waning as damage in the treated plots had increased to 7–10% of shoots by the last evaluation. ANOVA indicated that the effect of treatments was statistically significant at four sites through October of the first year, and at six of the seven through the second year ($P < 0.05$) (Fig. 1; Table 2).

There was also a tendency for the treatments to enhance survival on some sites—even during periods where no tip moth damage was present (Fig. 2; Table 3). The effect was statistically significant on three sites through most of the study period, and marginally significant ($P < 0.10$) at one other. Although we did not

Table 2. Percentage of loblolly pine terminals with tip moth damage in 2008–2009 and number of sites by sampling date where ANOVA showed a significant effect of treatment on percentage of damaged shoots ($\alpha = 0.05$)

Sample date	Treatment	Site name							Avg. (all sites) (%)	No. sites where $P < 0.05$
		ABSF	Burke	Clay	J City	McIvor	McKinney	PDCC		
June 2008	Check	0.00	9.01a	0.00	0.67	0.00	2.00	0.13	1.69	
	SilvaShield	No test	0.42b	0.00	No test	0.00	0.26	0.00	0.14	
	PTM	0.00	4.30c	0.00	0.00	0.00	1.15	1.16	0.94	
	Pr > *F*	n/a	0.0011	n/a	0.391	n/a	0.192	0.5507		1
Aug. 2008	Check	0.00	11.77a	1.91	26.01	0.56	4.88a	1.83	6.71	
	SilvaShield	No test	0.51b	0.00	No test	0.00	0.00a	0.00	0.10	
	PTM	0.00	0.25b	0.00	0.21	0.00	0.50a	0.00	0.14	
	Pr > *F*	n/a	0.0007	0.165	0.0189	0.4219	0.044	0.1391		3
Oct. 2008	Check	No data	21.77a	5.45	45.65	13.06a	39.08a	1.93	21.16	
	SilvaShield	No test	0.20b	0.00	No test	0.39b	3.97b	0.00	0.91	
	PTM	No data	0.56b	2.42	3.84	1.06b	5.90b	0.00	2.30	
	Pr > *F*	No data	0.0092	0.1513	0.0085	0.0004	0.0036	0.2134		4
June 2009	Check	4.16	21.40a	15.68a	44.82	8.72a	24.39a	53.42a	24.66	
	SilvaShield	No test	0.00b	0.78b	No test	0.61c	11.25b	5.90b	3.71	
	PTM	0.00	0.90b	2.04b	6.68	4.06b	18.57ab	4.74b	5.28	
	Pr > *F*	0.0097	<0.0001	0.0014	0.0016	0.0008	0.0335	0.0001		7
Aug. 2009	Check	8.93	49.23a	22.35a	28.65	23.39a	12.78a	60.10a	29.35	
	SilvaShield	No test	2.67b	0.33b	No test	2.55bc	3.18b	3.52b	2.45	
	PTM	0.34	7.77b	2.04b	1.09	10.49b	6.04ab	7.20b	5.00	
	Pr > *F*	0.0136	0.0013	0.0011	0.0036	0.0035	0.012	<0.0001		7
Oct. 2009	Check	34.14	45.82a	23.15a	22.37	39.53a	21.07	23.68a	29.96	
	SilvaShield	No test	7.74b	4.04b	No test	8.84c	11.98	3.70b	7.26	
	PTM	3.75	9.50b	4.36b	6.14	26.18b	17.65	1.03b	9.80	
	Pr > *F*	0.0172	0.0074	0.0038	0.0013	0.0003	0.1659	0.0008		6

Within sites and sampling dates with three treatments and $P < 0.5$, means followed by the same letter are not significantly different (Holm–Sidak multiple comparison test). n/a, not applicable.

Table 3. Percentage of survival of loblolly pine in 2008 and 2009 and number of sites by sampling date where ANOVA showed a significant effect of treatment on percent of damaged shoots ($\alpha = 0.05$)

Sample date	Treatment	Site name							Avg. (all sites) (%)	No. sites where $P < 0.05$, $P < 0.1$
		ABSF	Burke	Clay	J City	McIvor	McKinney	PDCC		
June 2008	Check	97.73	92.00a	45.00a	75.00	85.00	93.00	96.94a	83.52	
	SilvaShield	No test	100.00b	76.00b	No test	90.91	94.06	77.00b	87.59	
	PTM	98.95	98.00b	88.00b	79.00	96.00	90.91	86.00ab	90.98	
	Pr > *F*	0.8374	0.0078	0.0038	0.6578	0.1207	0.7793	0.0223		3,3
Aug. 2008	Check	92.78	90.00a	34.00a	63.00	81.00	91.00	91.84a	77.66	
	SilvaShield	No test	99.00b	75.00b	No test	89.90	91.09	74.00a	85.80	
	PTM	93.94	99.00b	85.00b	79.00	96.00	85.86	82.00a	88.69	
	Pr > *F*	0.5631	0.0283	0.0049	0.197	0.0605	0.7378	0.0471		3,4
Oct. 2008	Check	No data	87.00	33.00a	62.00	80.00a	91.00	89.80	73.80	
	SilvaShield	No test	99.00	75.00a	No test	89.90ab	91.09	74.00	85.80	
	PTM	No data	96.00	84.00b	79.00	96.00b	85.86	81.00	86.98	
	Pr > *F*	No data	0.0691	0.0046	0.1446	0.0419	0.7378	0.0531		2,4
June 2009	Check	88.78	87.00	27.00a	63.00	79.00a	88.00	88.78a	74.51	
	SilvaShield	No test	99.00	75.00b	No test	89.90ab	91.09	72.00b	85.40	
	PTM	92.00	96.00	83.00b	79.00	96.00b	85.86	80.00ab	87.41	
	Pr > *F*	0.229	0.0691	0.0028	0.1453	0.0382	0.7182	0.0387		3,4
Aug. 2009	Check	87.76	87.00	27.00a	63.00	79.00a	89.00	87.76	74.36	
	SilvaShield	No test	99.00	76.00b	No test	89.90ab	92.08	72.00	85.80	
	PTM	92.00	96.00	82.00b	79.00	96.00b	85.86	79.00	87.12	
	Pr > *F*	0.1801	0.0691	0.005	0.1453	0.0382	0.6633	0.1571		2,3
Oct. 2009	Check	86.73	87.00	27.00a	63.00	79.00a	89.00	87.76	74.21	
	SilvaShield	No test	99.00	76.00b	No test	89.90ab	93.07	72.00	85.99	
	PTM	92.00	96.00	83.00b	79.00	96.0b	85.86	79.00	87.27	
	Pr > *F*	0.1697	0.0691	0.0035	0.1453	0.0382	0.5645	0.2457		2,3

Within sites and sampling dates where there are three treatments and $P < 0.5$, means followed by the same letter are not significantly different (Holm–Sidak multiple comparison test).

intend to focus on pests other than tip moths when establishing this study, our observations indicated that on at least three sites, both insecticides significantly reduced mortality (Table 3) that was attributed to pales weevil based on close inspection of each dead seedling in the study. Both products increased plantation survival by an overall average of 12–13% after 2 yr. Average survival differences probably would have been more pronounced if not for the confounding affects of the PDCC site that unlike the other sites, showed higher survival in the check versus both treated plots, although these differences were not statistically significant (Table 3). A likely explanation for the survival numbers trending this way was random seedling mortality and poor growth throughout the site due to lack of chemical weed control, which led to some seedlings being smothered with no room to grow or obtain sunlight. Pales weevil was not a factor here and under these conditions the tip moth control became irrelevant.

The protection provided by the treatments resulted in a modest growth response, which was statistically significant on only a few of the sites (Table 4). On average, the gains in height, ground-line diameter, and volume index after 2 yr amounted to 9, 3, and 69%, respectively (Table 4). Once again, volume averages were partially confounded by the PDCC site, which was the only site where the average volume for the control trees was numerically greater than one of the two insecticide treatments, for the reasons suggested above. On average, the large per hectare volume gain was influenced more by the enhanced survival than by increased individual tree size. The SS treatment resulted in greater volume gains than PTM at the end of year 2, although these differences were not statistically significant.

Both fipronil (PTM) and imidacloprid (SS), therefore, demonstrated significant control of Nantucket pine tip moth damage throughout the two-year period of the study. In addition, volume gains due to both treatments were consistent across most sites, if not always statistically significant. These gains were more evident at sites that were more intensively-managed via site preparation and weed control. Previous literature suggests that intensively managed stands have more to gain from tip moth control due to lower levels of weed competition and faster growth rates (Berisford 1988, Nowak and Berisford 2000, Asaro et al. 2003). The lack of statistical significance for individual tree volume gain due to treatment was likely a function of large tree-to-tree size variation, which is typical in pine plantations, and relatively low tip moth damage levels in these study sites. Indeed, Asaro et al. (2006) suggest that an economic injury level for Nantucket pine tip moth probably exceeds 30% infested shoots on average. Although some sites saw individual generations that exceeded 30%, no sites had damage levels that averaged >30% over the 2-yr study. Furthermore, the full growth response from 2 yr of tip moth control may not be realized at the end of the second growing season, as tip moth treatment effects tend to increase through at least 5 yr (Cade and Hedden 1987).

Despite superior tree volume gains from the SS treatment compared with PTM after year 2, no statis-

Table 4. Height, ground line diameter (GLD), and vol of loblolly pine from 2008 to 2009 and no. of sites where ANOVA showed a significant effect of treatment on ht, diam, or vol index ($\alpha = 0.05$)

Sample date	Treatment	Site name							Avg. (all sites) (%)	No. sites where $P < 0.05$, $P < 0.1$
		ABSF	Burke	Clay	J City	McIvor	McKinney	PDCC		
Ht (m) 2008	Check	No data	0.34	0.34	0.36	0.41a	0.51a	0.34	0.38	
	SilvaShield	No test	0.35	0.34	No test	0.45ab	0.63b	0.29	0.41	
	PTM	No data	0.34	0.36	0.46	0.50b	0.59ab	0.30	0.42	
	Pr > *F*	n/a	0.64	0.7582	0.0201	0.0071	0.044	0.0866		3,4
Ht (m) 2009	Check	0.85	0.83	0.83	0.96	1.26a	1.55	0.77	1.01	
	SilvaShield	No test	1.01	0.90	No test	1.50b	1.75	0.79	1.19	
	PTM	0.87	0.91	0.97	1.13	1.49b	1.71	0.82	1.13	
	Pr > *F*	0.5545	0.0562	0.2396	0.2106	0.0077	0.2338	0.7582		1,2
GLD (cm) 2008	Check	No data	0.75	0.76ab	0.96	0.90a	1.32	0.65	0.89	
	SilvaShield	No test	0.71	0.69a	No test	0.96a	1.47	0.58	0.88	
	PTM	No data	0.69	0.84b	1.09	1.12b	1.42	0.60	0.96	
	Pr > *F*	n/a	0.41	0.027	0.0079	0.0052	0.5462	0.3918		3,3
GLD (cm) 2009	Check	1.08	1.93	1.36	1.93	2.31a	3.45	1.27	1.90	
	SilvaShield	No test	2.00	1.32	No test	2.50ab	4.03	1.16	2.20	
	PTM	1.07	1.89	1.61	2.33	2.82b	3.67	1.25	2.09	
	Pr > *F*	0.8735	0.53	0.102	0.0651	0.019	0.5836	0.7378		1,3
Vol index (cm^3/ha) 2008	Check	No data	55	17a	67	87a	217	35	79.49	
	SilvaShield	No test	54	38a	No test	126a	361	21	119.94	
	PTM	No data	48	65b	139	194b	300	25	128.46	
	Pr > *F*	n/a	0.63	0.0049	0.0115	0.0027	0.105	0.0666		3,4
Vol index (cm^3/ha) 2009	Check	268	927	148 a	713	1,674a	4,875	350	1,279.16	
	SilvaShield	No test	1,308	444b	No test	2,747ab	7,581	290	2,474.05	
	PTM	301	1,036	748b	1,439	3,420b	5,771	374	1,869.98	
	Pr > *F*	0.4885	0.0672	0.0039	0.105	0.0085	0.3889	0.4921		2,4

Within sites and sampling dates where there are 3 treatments and $P < 0.5$, means followed by the same letter are not significantly different (Holm-Sidak multiple comparison test). n/a, not applicable.

tically meaningful difference in efficacy between the two products was observed. The SS tablets were applied more consistently (one tablet per planting hole during planting), whereas the PTM treatments were applied using a hand-held spot gun at various times up to 1 wk after planting. This could have led to less consistent application and efficacy of PTM. Indeed, some data suggest that PTM is less effective if it is not spot applied to the planting hole immediately before inserting the seedling, rather than applying to the root zone some time after the seedling is put in the ground (D. Grosman, personal communication). Further studies are needed to determine the most effective way to maximize uptake of systemic fipronil by newly planted pine seedlings.

New systemic insecticide formulations continue to show promising results for controlling a variety of pests of southern pines such as seed and cone insects (Grosman et al. 2002), wood borers (Grosman and Upton 2006), and pine bark beetles (Grosman et al. 2009). In addition to Nantucket pine tip moth control, our data also suggest that both fipronil and imidacloprid protect against damage from pales weevil, although more much more extensive testing is needed to adequately demonstrate this. A systemic insecticide drawn up into the foliage and terminal buds to ward off pine tip moths, sap-sucking insects and defoliators would presumably also be present in the cambial tissues at concentrations that could inhibit debarking weevils. Indeed, insecticides used against a specific pest may have an additional impact on nontarget pests, resulting in improved growth or survival of the host plant that cannot be explained by suppression of the target pest alone. Aphids and scale insects are, in fact, listed on the labels of each of the tested products, as cited above. Therefore, growth gains might be realized by protecting against these pests as well, although damage due to sap-sucking insects would be difficult to measure and we saw no obvious evidence of these pests in the current study. Such an unexplained "insecticide growth effect" could be even more pronounced when using systemic products because application timing is not an issue and many potential insect pests could be exposed to lethal concentrations of insecticide throughout the growing season. In the current study, it was greater seedling survival rather than growth that led to meaningful per acre wood volume gains in the treated plots.

Systemic insecticides show promise for economical use in plantation forestry, particularly when there is a need to address multiple insect pest problems, environmental concerns with insecticide spray drift, or both. However, although the SilvaShield and PTM products were relatively easy to apply and showed effective and long-lasting control from one application, it is still not clear whether use of these products would be economical for routine use in southern pine plantation forestry. Common silvicultural practices in loblolly pine include intensive site preparation (US\$211/ha or US\$85/acre), tree planting (US\$171–221/ha or US\$69–89/acre), herbaceous weed control (US\$124/ha or US\$50/acre), and fertilization (US\$186/ha or US\$75/acre) (Borders and Bailey 2001, Huang et al. 2005). One recent comparison lists the product costs of PTM and SilvaShield as

US\$130/ha (US\$52.50/acre) and US\$228/ha (\$92/acre), respectively (Grosman 2010), even before adding the cost of labor to apply them. Until pine tip moth population dynamics and the value of pine responses can be more accurately predicted, these amounts would be prohibitive except in stands of high value or with substantial levels of anticipated tip moth damage based on adjacent stands or historical activity.

Acknowledgments

We thank MeadeWestvaco Corporation and Paul D Camp Community College, Franklin, VA, for site access; Mike Fleming of BASF for supplying the PTM Insecticide; Nate Royalty of Bayer Environmental Science for supplying the SilvaShield Forestry Tablets; and Scott Cameron and Don Grosman for an early review of the manuscript.

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Received 15 December 2010; accepted 27 May 2011.