Effects of Nantucket Pine Tip Moth Insecticide Spray Schedules on Loblolly Pine Seedlings

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ABSTRACT: *Frequent and prolonged insecticide applications to control the Nantucket pine tip moth,* Rhyacionia frustrana *(Comstock) (Lepidoptera:Tortricidae) (NPTM), although effective, may be impractical and uneconomical for commercial timber production. Timed insecticide sprays of permethrin (Pounce 3.2® EC) were applied to all possible combinations of spray schedules for three annual NPTM generations during the first, second, and first and second years following stand establishment. An optimal insecticide spray schedule that minimized the number of costly insecticide applications and maximized volume index in loblolly pine* (Pinus taeda *L.) was determined by applying a single spray during the first generation of the first and second years following planting. This schedule eliminates four sprays over a 2 yr period when compared to standard insecticide application schedules and has important implications toward establishing an integrated pest management program for this common regeneration pest. South. J. Appl. For. 24(2):106–111.*

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera:Tortricidae) (NPTM), is an important pest of Christmas tree and pine plantations in the eastern United States (Berisford 1988). The life cycle is synchronized with the primary host to produce a new generation of egg-laying adults with each new growth flush. The NPTM has two to five generations annually depending on climate (Berisford 1988). Three generations are common throughout the southeastern Piedmont and the North Carolina and Virginia Coastal Plain (Fettig et al. 2000).

Female moths deposit eggs singly on needles and shoots with a significantly greater proportion being laid on needles (McCravy and Berisford 1998). Late larval instars enter the lateral and terminal shoots where their feeding severs the vascular tissue and kills the apical meristem. Fifth instar larvae pupate and overwinter during the final annual generation within these damaged shoots. Larval feeding can cause shoot mortality and tree deformity (Berisford and Kulman 1967), height and volume reductions (Cade and Hedden 1987, Stephen et al. 1982), formation of compression wood (Hedden and Clason 1980), and occasional tree mortality (Yates et al. 1981). The tolerance of young trees to tip moth damage is initially low, but increases with age. Damage is most severe on seedlings and saplings less than 4 yr old (Berisford 1988). In the southeastern United States preferred hosts include loblolly (*Pinus taeda* L.), shortleaf (*P. echinata* Mill.), and Virginia (*P. virginiana* Mill.) pines.

The impact of this insect has become of increasing concern as standard silvicultural practices have become more intensive in commercial pine production. The associated silvicultural manipulations of herbaceous weed control, release, bedding and fertilization have shortened rotation lengths and increased volume yields (Pritchett and Smith 1972, Creighton et al. 1987), but have often elevated NPTM infestations (Berisford and Kulman 1967, Hertel and Benjamin 1977, Miller and Stephen 1983, Ross et al.1990). Insecticide applications are an effective control method if properly timed, but are only recently being considered as part of silvicultural prescriptions for intensively managed pine plantations. Models are available to predict optimal spray dates where three generations occur annually (Gargiullo et al. 1983, Fettig and Berisford 1999a). These models have reduced application frequencies to one carefully timed spray per generation (3/yr) and have increased insecticide efficacy. However, the models were initially designed to protect high-valued stands such as Christmas tree plantations from aesthetic damage resulting from NPTM infestations. Three insecticide applications per year may be impractical and/or uneconomical in commercial timber production where the primary objective is increased economic returns resulting from higher volume yields. Currently, the minimum number and timing of insecticide applications needed to maximize loblolly pine yield during the first 2 yr following stand establishment are unknown. Most studies indicate that any volume gains realized from tip moth control during early

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stand development are retained to harvest at conventional pulpwood and chip-and-saw rotation lengths (Hedden et al. 1981, Cade and Hedden 1987, C.W. Berisford, unpublished data).

Integrated pest management (IPM) programs attempt to reduce insect associated losses to acceptable levels using multiple techniques that are effective, economically viable, and ecologically compatible. The objective of this study was to develop a NPTM control program that maximizes growth returns in loblolly pine with the minimum number of insecticide applications during the first 2 yr following stand establishment. Such a finding could become an integral part of any IPM program established for the NPTM.

Materials and Methods

Study Locations

In 1997, two newly planted (1 yr old) and two 2 yr old plantations were selected as study sites in the Georgia Piedmont. The 1 yr old plantations were located near Bostwick, GA (Morgan County) and Greensboro, GA (Greensboro 1; Greene County). The 2 yr old plantations were located near Greensboro, GA (Greensboro 2 and 3). In 1998, three additional 1 yr old and four additional 2 yr old plantations were selected as study sites in the Georgia Piedmont and North Carolina and Virginia Coastal Plain. The 1 yr old plantations were located near Drewryville, VA (Southampton County), Franklin, VA (Southampton County), and Lexington, GA (Lexington 3; Oglethorpe County). The 2 yr old plantations were located near Como, NC (Hertford County), Emporia, VA (Greensville County) and Lexington, GA (Lexington 1 and 2). All sites had received herbaceous weed control (except Bostwick) and were planted with 1-0 loblolly pine seedlings. It was previously confirmed that three NPTM generations occurred in each region (Berisford et al. 1992, Fettig and Berisford 1999a).

Experimental Design

In 1997, three randomized complete blocks were established in each plantation. Each block consisted of eight randomly assigned plots corresponding with the number of treatments and contained 12 randomly selected trees (N = 1152). In 1998, five randomized complete blocks were established in each plantation. Each block contained eight plots and eight randomly selected trees within a plot (N = 2560). Tree locations were marked with a pin flag, mapped according to site and location, and revisited each generation according to the treatment schedule.

Insecticide Applications

The timing of insecticide applications was determined by monitoring male moth emergence for each generation with sex pheromone lures in Pherocon 1 C® sticky traps (Trece Inc., Salinas, CA), and accumulating degree-days after the detection of an average of one moth per trap per day using continuously recording biophenometers (Omnidata T151®; Dataloggers Inc., Logan, UT). Traps and biophenometer recordings were monitored every 4–5 days near Franklin, VA, Greensboro, GA, and Lexington, GA, until the appropriate degree-day spray prediction value was reached for each generation. Insecticides were applied at 188, 261, and 315 degree-days (°C) in North Carolina and Virginia and 204, 308, and 293 degree-days (°C) in Georgia for each of the three NPTM generations (Fettig and Berisford 1999a).

Insecticide applications included timed sprays of permethrin (Pounce 3.2® EC) applied with hand-pump backpack sprayers (Model 425; Solo®, Newport News, VA) at a rate of 0.6 ml of formulated product per liter of water. Applications were made to individual trees with solid cone nozzles until all foliage was moist. Treatments consisted of all possible combinations of insecticide spray schedules based on three annual NPTM generations including: (C) untreated control, (1) first generation, (2) second generation, (3) third generation, (1&2) first and second generation, (1&3) first and third generation, (2&3) second and third generation, and (A) all generations. Applications were made during the first year only at three sites (Table 1), second year only at six sites (Table 2), and both the first and second year following stand establishment at two sites (Table 3).

Damage and Growth Estimates

Damage estimates were taken on 30 randomly selected trees in Treatments C (untreated control) and A for each site during the pupal stage of each generation. The total number of shoots (i.e., > 10 linear cm of apical stem containing foliage) and number of NPTM infested shoots were recorded in the terminal plus top whorl of each tree. Damage was expressed as the percentage of damaged shoots in the terminal plus top whorl, which is highly correlated with whole-tree damage (Fettig and Berisford 1999b). Insecticide efficacy was expressed as the percent reduction between damage levels in the untreated control and Treatment A for each site and year and then averaged across all sites and years.

Growth was measured at the end of the third generation during 1997 and 1998 on all marked trees. Basal diameter (D) was measured with a caliper at 2.5 cm above ground surface. Height (H) was measured from the root collar to the tip of the

Table 1. Mean percentage of damaged shoots in the top whorl (± SE) for untreated (control) and permethrin treated (Treatment A) loblolly pine trees sprayed at age 1 (1998) in a study to determine optimal *Rhyacionia frustrana* insecticide spray schedules.

	Generation					
	1		2		3	
Location	Control	Treated	Control	Treated	Control	Treated
Drewryville, VA	16.0 ±7.5[1]	8.8 ± 5.5	24.6 ± 6.0	4.0 ± 4.0	60.5 ± 7.0	31.8 ± 5.8
Franklin, VA	9.5 ± 4.3	4.0 ± 4.0	65.3 ± 7.9	31.3 ± 7.8	44.2 ± 7.5	24.2 ± 5.0
Lexington 3, GA	5.4 ± 2.7	0.0 ± 0.0	26.9 ± 7.1	4.0 ± 4.0	47.2 ± 7.0	16.0 ± 5.7
Mean	10.3	4.3	38.9	13.1	50.6	24.0

[1] n = 30.

Table 2. Mean percentage of damaged shoots in the top whorl (± SE) for untreated (control) and permethrin treated (Treatment A) loblolly pine trees sprayed at age 2 (in 1997 or 1998) in a study to determine optimal *Rhyacionia frustrana* insecticide spray schedules.

	Generation					
	1		2		3	
Location	Control	Treated	Control	Treated	Control	Treated
Como, NC	65.5 ± 5.0[1]	2.6 ± 1.6	54.0 ± 7.3	30.9 ± 6.7	48.7 ± 6.8	13.9 ± 3.5
Emporia, VA	63.7 ± 5.7	1.6 ± 1.1	30.4 ± 5.2	6.7 ± 2.6	65.9 ± 5.8	30.9 ± 6.2
Greensboro 2, GA[2]	13.9 ± 3.6	0.0 ± 0.0	16.8 ± 4.0	2.8 ± 1.4	26.3 ± 5.7	15.6 ± 5.3
Greensboro 3, GA[2]	12.6 ± 3.7	1.7 ± 1.2	12.0 ± 3.1	2.8 ± 1.6	20.8 ± 4.6	11.1 ± 3.3
Lexington 1, GA	59.6 ± 6.5	0.0 ± 0.0	80.6 ± 4.1	6.7 ± 3.0	92.4 ± 4.6	58.8 ± 6.4
Lexington 2, GA	45.5 ± 5.3	0.0 ± 0.0	63.0 ± 5.9	2.1 ± 1.2	52.4 ± 6.7	27.1 ± 5.0
Mean	43.5	1.0	42.8	8.7	51.1	26.2

1 $n = 30$.
2 Plantations treated during 1997.

terminal leader using a cm graduated height stick. These values were later used to compute a volume index (D^2H) for each treatment. This index is highly correlated with aboveground biomass (Ross et al. 1990). The growth data were analyzed as a randomized complete block design and compared with the Tukey test for separation of treatment means (SAS Institute 1989, Sokal and Rohlf 1995).

Results and Discussion

Mean damage levels on untreated plots ranged from a low of 1.9% to a high of 92.4% (Tables 2 and 3). The lowest damage levels were observed during the first NPTM generation immediately following planting in both 1997 and 1998 (Tables 1 and 3). Tip moth recruitment to new stands may be limited by the proximity of stands within susceptible age classes and the NPTM densities within these stands. Since the NPTM life cycle is closely linked to host phenology, reductions in population growth may also occur initially as a result of delayed or asynchronous growth flushes following planting. In general, NPTM densities in untreated plots increased throughout the second and third NPTM generation following stand establishment and reached maximum densities during the second year (Tables 1–3).

Insecticide efficacy in both 1 and 2 yr old stands decreased throughout the year from 90.4% control in the first generation to 77.6% and 55.5% control in the second and third generations. Spray timing maximizes control by specifically targeting first and second instar larvae. These stages are most susceptible to control due to their small size, presence on the needle or shoot surface, and movement over sprayed areas when in search of new feeding sites (Berisford et al. 1984). Decreasing spray efficacy is commonly observed throughout the year due to increasing asynchrony among susceptible NPTM life stages in later generations (Fettig et al. 1998). Control of the first NPTM generation when insecticide efficacy is highest is also of particular importance in resistance management by limiting the proportion of insects that escape sublethal exposures.

Few significant differences were observed among treatment means when insecticides were applied to age 1 trees (Figure 1). Treatment A (all generations treated) had significantly larger diameter and volume estimates than the untreated control. No other significant differences were observed among the remaining treatment means. This suggests that spraying NPTM infestations only during the first year following stand establishment is ineffective unless every generation is included in the control schedule. We observed a 22.1% increase in diameter and 63.1% increase in volume index by applying Treatment A (Figure 1).

More significant differences were observed among treatment means when insecticides were applied to age 2 trees (Figure 2). Treatment 1&3 (generations 1 and 3), Treatment 2&3 (generations 2 and 3) and Treatment A had significantly larger diameter, height and volume estimates than the untreated control (Figure 2). No significant differences were observed among Treatments 1&3, 2&3, and A. At least two insecticide sprays were required to produce a significant difference in all three growth measurements. An optimal insecticide spray schedule for controlling NPTM infestations

Table 3. Mean percentage of damaged shoots in the top whorl (± SE) for untreated (control) and permethrin treated (Treatment A) loblolly pine trees sprayed at age 1 (1997) and 2 (1998) in a study to determine optimal *Rhyacionia frustrana* insecticide spray schedules.

	Generation					
	1		2		3	
Location	Control	Treated	Control	Treated	Control	Treated
1997						
Bostwick, GA	4.4 ± 2.79[1]	0.0 ± 0.0	8.4 ± 3.4	1.5 ± 1.1	13.6 ± 3.1	4.8 ± 2.5
Greensboro 1, GA	1.9 ± 1.4	0.0 ± 0.0	13.6 ± 3.7	6.1 ± 3.8	11.4 ± 4.8	1.7 ± 1.7
1998						
Bostwick, GA	18.6 ± 3.6	1.5 ± 1.0	49.6 ± 7.2	3.1 ± 1.8	85.2 ± 4.1	37.1 ± 6.2
Greensboro 1, GA	48.0 ± 5.9	0.0 ± 0.0	54.7 ± 7.1	7.0 ± 3.5	86.1 ± 4.8	32.5 ± 7.1
Mean	18.2	0.4	31.6	4.4	49.1	19.0

1 $n = 30$.

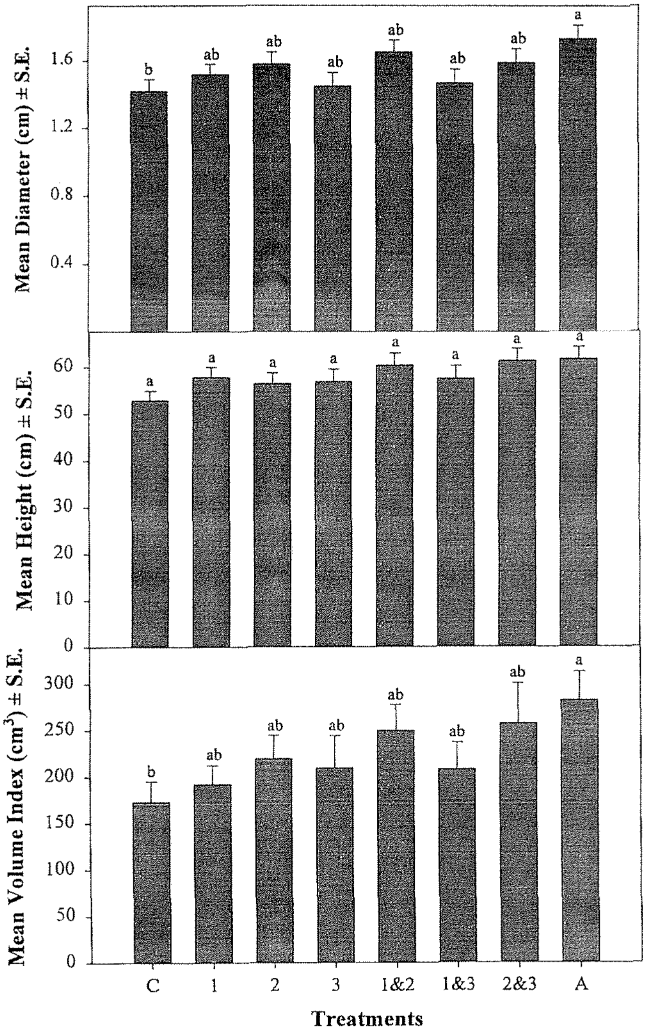

Figure 1. Mean size (± S.E.) of 1 yr old loblolly pine seedlings sprayed with permethrin to control NPTM infestations at age 1 only. Treatments represent all possible combinations of insecticide spray schedules based on three NPTM generations including: (C) untreated control, (1) first generation, (2) second generation, (3) third generation, (1&2) first and second generation, (1&3) first and third generation, (2&3) second and third generation, and (A) all generations. Means followed by the same letter within a growth estimate are not significantly different ($P > 0.05$; Tukey test).

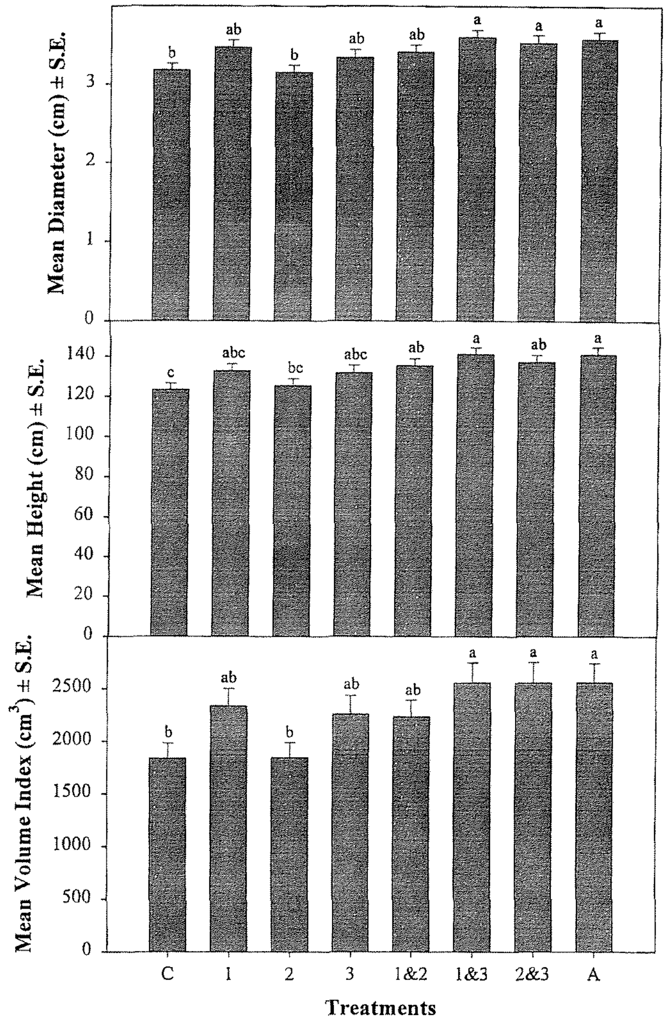

Figure 2. Mean size (± S.E.) of 2 yr old loblolly pine saplings sprayed with permethrin to control NPTM infestations at age 2 only. Treatments represent all possible combinations of insecticide spray schedules based on three NPTM generations including: (C) untreated control, (1) first generation, (2) second generation, (3) third generation, (1&2) first and second generation, (1&3) first and third generation, (2&3) second and third generation, and (A) all generations. Means followed by the same letter within a growth estimate are not significantly different ($P > 0.05$; Tukey test).

in age 2 trees with insecticide applications applied during the second year includes either spraying the first and third or second and third generations thereby eliminating one spray without any significant reduction in tree growth. We observed a 13.4% increase in diameter, 14.5% increase in height, and 39.0% increase in volume by applying Treatment 1&3. Treatment 2&3 resulted in a 12.1% increase in diameter, 11.2% increase in height, and 38.9% increase in volume (Figure 2).

Significant differences were observed among treatment means when insecticides were applied to the same trees at both age 1 and age 2 (Figure 3). Treatment 1 had a significantly larger height estimate than the untreated control, and a significantly larger volume index than four other treatments including the control (Figure 3). We observed a 10% increase in diameter, 20.5% increase in height, and 74.5% increase in volume index by applying Treatment 1 during the first 2 yr following stand establishment (Figure 3). This is the largest increase in volume index observed relative to the untreated control.

The application of timed permethrin sprays during the first generation of both the first and second year following stand establishment appears to be the optimal insecticide spray schedule for controlling NPTM infestations during this critical time. Insecticide efficacy is greatest during the first generation, and coincides with the time when recurrent growth species such as loblolly pine typically have their largest growth flush of the year (Oliver and Larson 1996). Recently it has been found that control of the first generation also has an extended benefit. In a study conducted in the Georgia Piedmont, trees treated with permethrin during the first NPTM generation had significantly less NPTM damage at the end of the second generation when compared to adjacent untreated controls (Coody et al. 2000). This sug-

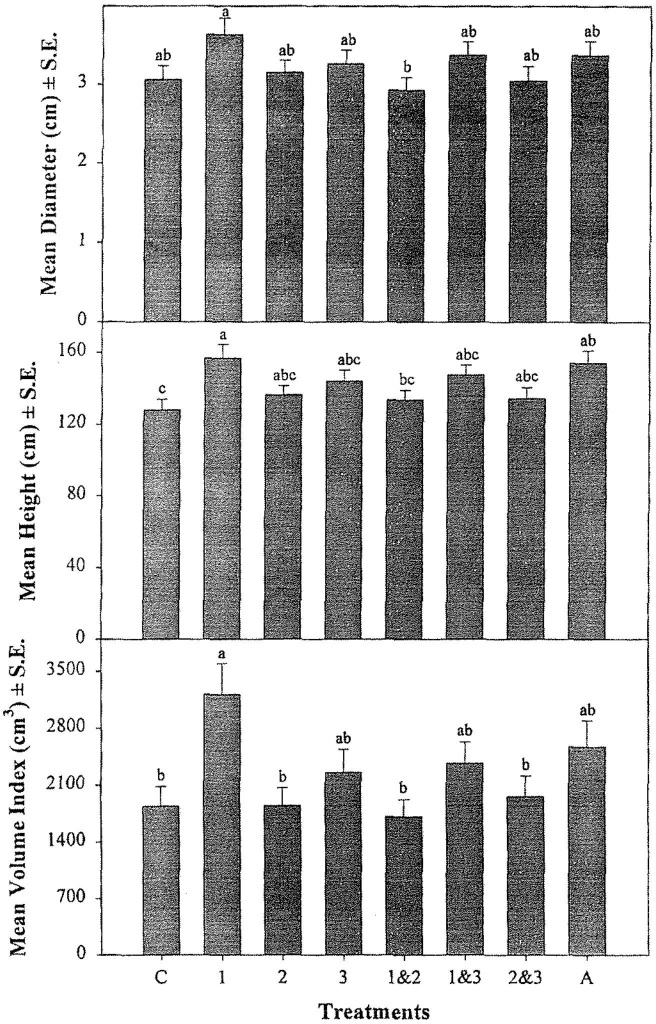

Figure 3. Mean size (± SE) of 2 yr old loblolly pine saplings sprayed with permethrin to control NPTM infestations at both ages 1 and 2. Treatments represent all possible combinations of insecticide spray schedules based on three NPTM generations *including:* (C) untreated control, (1) first generation, (2) second generation, (3) third generation, (1&2) first and second generation, (1&3) first and third generation, (2&3) second and third generation, and (A) all generations. Means followed by the same letter within a growth *estimate are not significantly* different (*P* > 0.05; Tukey test).

gests that previous NPTM attacks predispose trees to heavier attacks during later generations, possibly due to bud proliferation from previous attacks, changes in host physiology, or simply that females emerging from infested trees mate and deposit eggs on the same trees. Control of the first generation of the first year may also be important in reducing recruitment from adjacent stands by reducing the number of suitable ovipositional sites (i.e., bud proliferation resulting from NPTM attacks) and calling females.

Currently, most NPTM control programs target at least the first and second year following planting and insecticides are repeatedly applied to control each NPTM generation. On poor sites damage may be prolonged as long as trees remain in susceptible height classes (< 3.5 m) requiring additional insecticide applications during the third and possibly fourth year. Our data suggests it may be unnecessary to control each NPTM generation to increase volume yields. The optimal insecticide spray schedule program for a three generation NPTM phenology would include a single first generation spray during the first 2 yr following planting. This would reduce the current practice by four sprays over the 2 yr period, which would be both economically and ecologically beneficial, two important criteria for an integrated pest management system. However, it is currently unknown what levels of NPTM damage result in significant growth losses, and what variations will occur in that damage threshold with respect to tree age, genetics, site productivity, and edaphic factors.

Microsite variability can also have profound impacts on seedling establishment and growth and therefore may mask potential gains from NPTM control. This variation may account for some of the large differences observed among treatment means that were not statistically significant ($P > 0.05$). For example, although the volume estimates for Treatments C and A (Figure 3) were not statistically different, a substantial increase in volume (≈ 40%) was observed by applying this treatment. Likewise, although Treatment 1 (Figure 3) is the optimal insecticide spray schedule, its mean should not be statistically greater than other treatments which also include a first generation spray (Treatments 1&2, 1&3, A). However, trees in Treatment 1&2 had significantly less volume than Treatment 1, which must result from variability that cannot be attributed to NPTM control. It may also be a function of the limited number of plantations included in this study where insecticides were applied during the first 2 yr following stand establishment. The results presented here may be limited to the NPTM densities encountered in these studies and could vary depending on site and edaphic factors. Further studies will be required to determine if these results are applicable on a more regional basis.

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