Long-Term Effects of Pine Tip Moth (Lepidoptera: Tortricidae) Control, Vegetation Control, and Fertilization on Growth and Yield of Loblolly Pine, *Pinus taeda* L. [1]

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J. Entomol. Sci. 48(1): 23-35 (January 2013)

Abstract Studies were conducted in Georgia and North Carolina to determine the long-term growth impact of pine tip moth, *Rhyacionia* spp., attacks on loblolly pines which had been treated with different combinations of insecticides for tip moth control, herbicides for control of competing vegetation, and fertilizer. Height, diameter, and volume responses were significantly greater for tip moth and weed control at age 5, both in Georgia and North Carolina. There was no evidence of a positive response to fertilizer. The largest responses were due to tip moth control, which was the only treatment that retained a significant response through the termination of the study at age 15 in Georgia and age 20 in North Carolina. Stand volumes continued to increase on the tip moth control plots throughout the study with average gains of 3.1 m^3/ha/yr (43.8 ft^3/acre/yr) at the Georgia site at age 15 and 3.2 m^3/ha/yr (45.8 ft^3/acre/yr) at age 20 at the North Carolina site. Trees receiving tip moth control also had significantly better form than untreated trees when evaluated at age 5, which may be reflected in higher quality and more valuable forest products at harvest. Treatment responses observed in this study clearly show that tip moth control can provide benefits equal to or greater than other commonly used cultural treatments, and may be necessary to realize anticipated gains from intensive management of loblolly pine plantations when tip moth damage is heavy.

Key words *Rhyacionia*, pine tip moth, growth impact, *Pinus taeda*

Pine tip moths, *Rhyacionia* spp., often cause significant damage to loblolly pines, *Pinus taeda* L., during the early years of plantation establishment in the southern United States. Tip moth larvae destroy growing buds and shoots, causing tree deformation, reduced height growth and occasional tree mortality (Yates 1960). Most damage in pine plantations is caused by the Nantucket pine tip moth, *R. frustrana* (Scudder *in* Comstock, 1880) (Young et al. 2006), which is one of the most ubiquitous pests of young pines in the South (Berisford 1988, Asaro et al. 2003). The pitch pine tip moth, *R. rigidana* (Fernald), and the subtropical pine tip moth, *R. subtropica* Miller, are often sympatric with *R. frustrana*, but they are usually much less abundant and cause relatively

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little damage (Miller and Wilson 1964, Baer and Berisford 1975). In the South, the favored hosts for both *R. frustrana* and *R. rigidana* are loblolly pine and shortleaf pine, *P. echinata* (Miller). Slash pine, *P. elliottii* (Engelmann), although occasionally attacked during stand establishment, is highly resistant to both *R. frustrana* and *R. rigidana* attacks. However, slash pine is the preferred host for *R. subtropica* (Powell and Miller 1978, Berisford et al. 1992). Although the other species may occasionally be locally abundant, Nantucket pine tip moth is currently the only economically important species in the southeastern Piedmont and Coastal Plain where it may have 3 - 5 generations annually (Powell and Miller 1978).

Several studies have demonstrated that tip moth damage can lead to significant reductions in early tree growth (Warren 1964, Beal 1967, Lashomb et al. 1978, Berisford et al. 1989, Fettig el al. 2000, Nowak and Berisford 2000, Hedden 2002, Asaro et al. 2006). Hedden (1998) summarized many of the tip moth impact studies by comparing growth measurements with and without tip moth control at various ages and found that tip moth damage on average reduced height growth by 73 cm (2.4 ft) and diameter by 1.3 cm (0.5 in). He also concluded that these differences were maintained through time, by comparing the growth impact of 67.1 cm (2.2 ft) on trees 5 - 8 years old with an impact of 79.2 cm (2.6 ft) on trees 12 - 16 years old. However, the long-term impact of tip moth attack on tree growth is still controversial, as relatively few studies have been carried beyond early stand development. Beal (1967) reported that trees in loblolly and shortleaf pine plantations which had been sprayed with insecticides to prevent tip moth attacks grew significantly more than untreated trees during the first 6 years after planting. However, this effect was not found in all stands. Measurement of these same stands at age 16 found that growth differentials between protected and unsprayed trees, while still present, had decreased considerably (Williston and Barras 1977). Mean tree heights were 13.0 m (42.7 ft) for treated trees and 11.6 m (38.1 ft) for untreated checks, and stem volumes averaged 150 m^3 /ha (2144 ft^3/acre) for treated loblolly and 129 m^3/ha (1844 ft^3/acre) for untreated trees. Burns (1975) found that 10 years after planting on northeast Florida sandhills, loblolly pines protected from tip moth were 2.8 m (9.2 ft) taller, about 3.81 cm (1.5 in) larger in diameter at breast height (DBH) and contained almost 3 times as much wood as unprotected pines. Cade and Hedden (1987) reported that loblolly pines protected from tip moth attack for 3 years after planting in Arkansas had 12.7 m^3/ha (182 ft^3/acre) more stem volume than unprotected trees at age 12.

Technological developments in pine plantation management and tree improvement programs within the last 3 decades have dramatically increased rates of growth. For example, Schmidtling (1984) found that cultural treatments as well as genetic differences affected all measures of growth through 22 years in loblolly pine. Fertilization combined with cultivation to reduce competition produced large growth gains whereby trees receiving cultivation and high rates of fertilization averaged 7.8 m taller than untreated checks. He concluded that early cultivation combined with fertilization was analogous to a long-term change in site quality. Some studies have suggested that significant interactions may occur among fertilization, chemical vegetation control, and tip moth control (Terry et al. 1984, Nowak et al. 2003).

The influence of stand management practices or growing conditions on tip moth infestations and subsequent tree damage has been evaluated several times. Wakeley (1928) stated that, "There is definite evidence that growing trees in dense stands minimizes the damage." Beal et al. (1952) and Berisford and Kulman (1967) found that loblolly pine plantations had heavier tip moth infestations than stands the same age and density but which had originated from natural reproduction. Hansbrough (1956) showed that tip moth infestations in loblolly pine plantations were heaviest in those with the widest tree spacings. Several observers have suggested that woody and/or herbaceous vegetation may act as mechanical barriers to tip moths (Graham and Baumhofer 1927, Beal el al. 1952, Foil et al. 1961, Warren 1963). Hertel and Benjamen (1977), White et al. (1984), and Hood et al. (1988) found that tip moth infestation densities were positively correlated with intensity of site preparation. It has been suggested that competing vegetation may favor natural enemies by maintaining high humidity, reducing isolation and providing pollen and/or nectar as nutrient sources (McCravy and Berisford 2001).

Intensive management of southern pines typically includes thorough mechanical site preparation and one or more herbicide applications plus fertilization on some sites. Although these practices increase tree growth, sometimes dramatically, they may exacerbate tip moth attacks which can prevent full realization of potential growth (Ross et al. 1990, Nowak and Berisford 2000). We initiated a study in 1985 to evaluate the long-term effects of different combinations of vegetation control, tip moth control and fertilization on growth and form of loblolly pine (Berisford et al. 1989). We report here the results from one installation in Georgia through 15 years and another in North Carolina through 20 years (after planting).

Materials and Methods

Research sites were selected in the upper Coastal Plain in Washington Co., GA (Lakeland soil, 25 yr native site index 57) and the Coastal Plain in Gates Co., NC (Leaf soil, 25 yr native site index 64). The Georgia site was planted in January, and the North Carolina site was planted in March 1985 with improved 1 - 0 bareroot loblolly pine seedlings following operational mechanical site preparation. The North Carolina site was also bedded. Four complete randomized blocks were delineated at each site. At the Georgia site, each block contained 6 treatment plots of approx.100 trees each (9 rows by 11 - 12 planting spaces) with the interior 25 trees (5 rows × 5 spaces) designated as measurement trees. Tree spacing was 1.8 m (6 ft) between trees within rows and 3.7 m (12 ft) between rows (1495 trees/ha (605 trees/acre)). At the North Carolina site, each block contained 4 treatment plots of approx. 117 trees each (9 rows by 13 trees) with the interior 35 trees of each plot (5 rows × 7 spaces) designated as measurement trees. Tree spacing was 2.1 m (7 ft) between trees within rows and 2.7 m (9 ft) between rows (1707 trees/ha (691 trees/ac)). Treatments were randomly assigned to plots. The Georgia site included: (1) untreated (Check), (2) tip moth control (TMC), (3) weed control and fertilizer (WC+Fert), (4) tip moth control, weed control, and fertilizer (TMC+WC+Fert), (5) tip moth control and weed control (TMC+WC), and (6) tip moth control and fertilizer (TMC+Fert). The North Carolina treatments were: (1) untreated (Check), (2) herbaceous and woody competition control (WC), (3) tip moth control (TMC), and (4) tip moth control and weed control (TMC+WC). Fertilization was excluded from the treatment matrix at the North Carolina site since the entire plantation received fertilizer in December 1984, prior to planting, to correct a phosphorus deficiency. Also, site quality is exceptionally high in this area, which further negated the need for additional fertilization. However, both sites had three treatments in common: check, tip moth control, and tip moth + weed control.

Plots which received herbaceous weed control at the Georgia site were treated at planting time with hexazinone (Velpar® @ 0.56 kg/ha) and sulfometuron (Oust® @

0.21 kg/ha) applied in a 1.22 m wide band centered over each row. The North Carolina site was treated in April of year 1 with a banded application of oxyfluorfen (Goal® 1.6E @ 1.1 kg/ha) plus sulfometuron (Oust® @ 0.21 kg/ha) and in year 2 with a banded application of hexazinone (Velpar® L @ 2.3 L/ha) plus sulfometuron (Oust® @ 0.14 kg/ha). In year 3, triclopyr (Garlon® 4) basal spray was applied for hardwood control and glyphosate (Roundup®) and sulfometuron (Oust® @ 0.14 kg/ha) was banded between rows.

Fertilized plots received 10 - 10 - 10 (N,P,K) fertilizer at 550 kg/ha on the Georgia site, and all plots in the North Carolina site received phosphorus (TSP) at 280 kg/ha. Tip moths were controlled for 3 yrs at both sites. Tip moth control plots in Georgia were treated in the first year with a soil application of carbofuran (Furadan 15G®) at a rate of 0.75 g ai/tree. Subsequent control (years 2 & 3) was by 4 annual foliar applications of fenvalerate (Pydrin® 2.4E) in a 0.10% solution. Foliar applications were timed by a spray timing model based on pheromone trap catches and accumulated degree-days (Gargiullo et al. 1985). The North Carolina trees in tip moth control treatment plots received 2 applications of Furadan granules (1 g ai/tree in March and July) plus 2 fenvalerate (0.25% ai) applications (Sept and October) in year 1. In year 2, treated trees received 3 applications of carbofuran (0.9 g ai/tree in April and May and 3.6 g ai/tree in June) plus 1 fenvalerate spray (0.25% ai) in late August. In year 3, treated trees received 1 application of carbofuran (4.5 g ai/tree in May) and 2 fenvalerate sprays (0.25% ai) in June and late July.

At the end of each of the first 3 growing seasons at the Georgia site and first 2 growing seasons at the North Carolina site, all the shoots in the top 2 whorls were scored as infested or uninfested. Damage was expressed as percent infested shoots in the top 2 whorls, which is often highly correlated with terminal and whole tree damage (Fettig and Berisford 1999a). Tip moth control treatments and damage estimates were discontinued after the third growing season. Infestations at the Georgia site were considered to be insignificant (<8%) by the fourth year.

Following the sixth growing season all plots in 2 blocks were thinned at the Georgia site. The thinnings removed approx. 40% of the stems, but thinning favored removal of diseased and obviously inferior trees, such that they represented less than 30% of the volume.

Tree heights and diameters at breast height (DBH) were measured at ages 5, 10, 12 and 15 at the Georgia site, after which further monitoring was discontinued due to disruption by logging activity in the study area. Measurements were taken at ages 5, 10, 15, and 20 in North Carolina. Tree form was evaluated at the Georgia site at the end of the third and fifth growing seasons by the method of Berisford and Kulman (1967). Four form classes were based on the numbers of forks present per tree as follows: (1) no forks, (2) 1 fork, (3) 2 - 4 forks, and (4) 5 or more forks. A fork was defined as a node with one or more laterals exceeding one half the diameter of the main stem.

Treatment means for tip moth damage and tree form were analyzed with ANOVA (alpha=0.05). Means were separated by Fisher's LSD test when the assumptions of normality and equal variances were met. The Kruskall-Wallis ANOVA on ranks was performed for data not meeting the appropriate assumptions.

Height and diameter measurements were used to calculate mean stem volume for each treatment using the formula of Pienaar et al. (1987). Whole tree volumes were calculated for individual trees using the Lower Coastal Plain (Flatwoods) equation for the NC site and the Upper Coastal Plain model for the GA site.

The analysis of tree growth parameters for the Georgia location was complicated by the thinning in 2 blocks of the study at age 6. Uneven, chance removals could cause differences in per hectare attributes that are due to thinning procedure rather than treatment effect. For instance, a chance difference in removals of 1 tree could change volume per hectare by about 5%. This was handled by performing the analysis on average tree attributes to understand treatment effects. A best estimate of what this might be in terms of volume per hectare is calculated based on an average number of trees per hectare for thinned and unthinned treatments and assumes that treatments do not differ in terms of mortality.

Reliable estimates of mortality are not available for the Georgia location between the time of thinning and the year 10 assessments, but a preliminary analysis found that trees per hectare did not differ by treatment on unthinned plots. Thinned treatments averaged 48 - 60% of the original trees present (where thinning targeted 40% removals) and unthinned treatments averaged 94 - 98% of the originals present at age 12. Density (trees per hectare) was not used as a covariate because preliminary analysis determined that it was not significant as a covariate in the analysis of average tree DBH, basal area, and volume.

Analysis of variance was performed for the Georgia location using a linear model as a randomized block design except that block effects were partitioned as though blocks were nested within the thinning regimen. The tests for thinning used the variation of blocks within thinning as the error term. This structure is similar to a split-plot design in that the test for thinning is not very powerful, but it allows a test of interaction between thinning and other treatments. The analysis was performed to account for the unequal subclass numbers (different number of trees on thinned and unthinned plots), and least square means are reported (Milliken and Johnson 1992). The North Carolina location was analyzed as a randomized complete block design. There were no significant interactions among weed control, fertilization, and tip moth control at either location for tree response variables. Treatment means are listed but not compared using a means comparison test due to the lack of interaction. Instead, the average response to each main effect is listed with its level of significance indicated.

Results and Discussion

Tip moth damage and tree form – Ages 1 - 5. Tip moth control was effective at both sites. Mean infestation rate for treatments not receiving tip moth control was 58% for years 1 - 3 at the Georgia site and 76% for years 1 - 2 at the North Carolina site, whereas mean infestation rate in plots receiving tip moth control averaged 6% at both sites (Table 1). Infestations in plots receiving weed control or weed control plus fertilizer were not significantly different from untreated checks at either site. There were significant differences among treatments in tree form through age 5 (Table 1). Treatments which included tip moth control had an average form rating of 1.1 at age 3, which was significantly better ($P < 0.05$) than all other treatments which averaged 3.1. Although differences in form had decreased by age 5 due to the trees growing beyond the stage where they were susceptible to heavy tip moth attack, trees protected from attack still had significantly better form than unprotected trees (Table 1).

Georgia location growth responses – Ages 5 - 15. Trees at the Georgia location responded positively to both tip moth control and weed control, and responses were additive. There was no evidence of a positive response to fertilizer. The 6 treatments included the base treatments of no treatment (Check), TMC, WC+Fert, and

Table 1. Mean percent of shoots infested by tip moths at the end of the first 2 and 3 growing seasons at the North Carolina and Georgia sites, respectively, and mean form class at age 3 and 5 at the Georgia site.

	Percent Tip Moth Infestation		Tree Form Class	
	Georgia Site	North Carolina Site	Georgia Site	
Treatment*	Age 1 - 3	Age 1 - 2	Age 3	Age 5
Check	62a**	73a	3.2a	2.9a
WC	-	79a	-	-
WC+Fert	53a	-	3.1a	2.7ab
TMC	6c	4b	1.1b	2.1c
TMC+WC+Fert	5c	-	1.1b	2.0c
TMC+WC	11b	8b	1.1b	2.2bc
TMC+Fert	3c	-	1.0b	2.2bc

*Treatments: WC = herbicide weed control, Fert = establishment fertilization, TMC = tip moth control for three years.
**Values followed by the same letter are not significantly different (alpha-0.05).

TMC+WC+Fert. The 2 additional treatments of TMC+WC and TMC+Fert allowed tests to determine if the response to Fert+WC was due mostly to fertilization or weed control. The test for weed control compared the average of TMC+WC and TMC+WC+Fert to the average of TMC and TMC+Fert. The test for fertilization compared the average of TMC+Fert and TMC+WC+Fert to the average of TMC and TMC+WC. Further tests indicated that there were no significant interactions among these cultural treatments and no significant interactions between these treatments and thinning.

The largest responses in both diameter (DBH) and total height were due to tip moth control. In terms of main effects, diameter response to tip moth control was 1.5 cm (0.6 in) at year 5 and increased to 2.0 cm (0.8 in) by year 15. Diameter response to both weed control + fertilization and weed control alone was 1.3 cm (0.5 in) at year 5 and 1.0 cm (0.4 in) by year 15. There was no significant response to fertilization (Table 2). There were significant height responses to tip moth control, fertilization + weed control, and weed control at year 5, but only height response to tip moth control remained significant at later ages. Tip moth control provided the largest height response among all cultural treatments averaging 91.4 cm (3.0 ft) at age 5 and increasing to 137.2 cm (4.5 ft) by age 15.

Average tree volume increased through age 15 at the Georgia location for all cultural treatments compared with the untreated check (Fig. 1A), but this increase was only significant for tip moth control at age 15 (Table 2). Estimates of volume per hectare gained from tip moth control for thinned (864 trees/ha (350 trees/acre)) and unthinned (1284 trees/ha (520 trees/acre)) treatments were 45.9 and 46.1 m^3/ha (656 and 659 ft^3/acre), respectively, with an average of 46 m^3/ha (657 ft^3/acre) (Table 4). This equates to 3.1 m^3/ha/yr (43.8 ft^3/acre/yr).

Table 2. Mean diameter (DBH), height, and individual tree volume by treatment at ages 5 and 15 for the Georgia site.

	Year 5			Year 15		
Treatment	DBH (cm)	Height (m)	Volume (dm^3)	DBH (cm)	Height (m)	Volume (dm^3)
1. Check	5.1	3.8	5.1	14.0	13.0	100.5
2. TMC	6.4	4.6	9.1	16.3	14.4	146.6
3. WC+Fert	5.8	4.4	8.2	15.0	13.1	120.6
4. TMC+WC+Fert	7.9	5.4	15.8	17.0	14.5	163.3
5. TMC+WC	8.4	5.5	17.5	17.3	14.3	170.9
6. TMC+Fert	7.4	5.2	13.3	16.0	14.8	153.1
Treatment Effect	Response Estimates[1,2]					
TMC	1.5**	0.9**	5.7**	2.0**	1.4**	44.4**
WC+Fert	1.3**	0.7**	4.8**	1.0 ns	0.2 ns	18.8 ns
WC	1.3**	0.6**	5.4**	1.0*	–0.2 ns	17.3 ns
Fert	0.3 ns	0.2 ns	1.1 ns	0.3 ns	0.3 ns	–0.6 ns
Thin	–	–	–	1.3 ns	–0.1 ns	19.0 ns

[1]ns = not significantly different from no response at $P = 0.05$, * = significant at $P < 0.05$,
** = significant at $P < 0.01$.
[2]Average responses for main effects in terms of treatment numbers in GA are:
TMC=(2 + 4 - 1-3)/2, WC+Fert=(3 + 4 - 2-1)/2, WC=(4 + 5 - 2-6)/2, Fert=(4 + 6 - 2-5)/2.

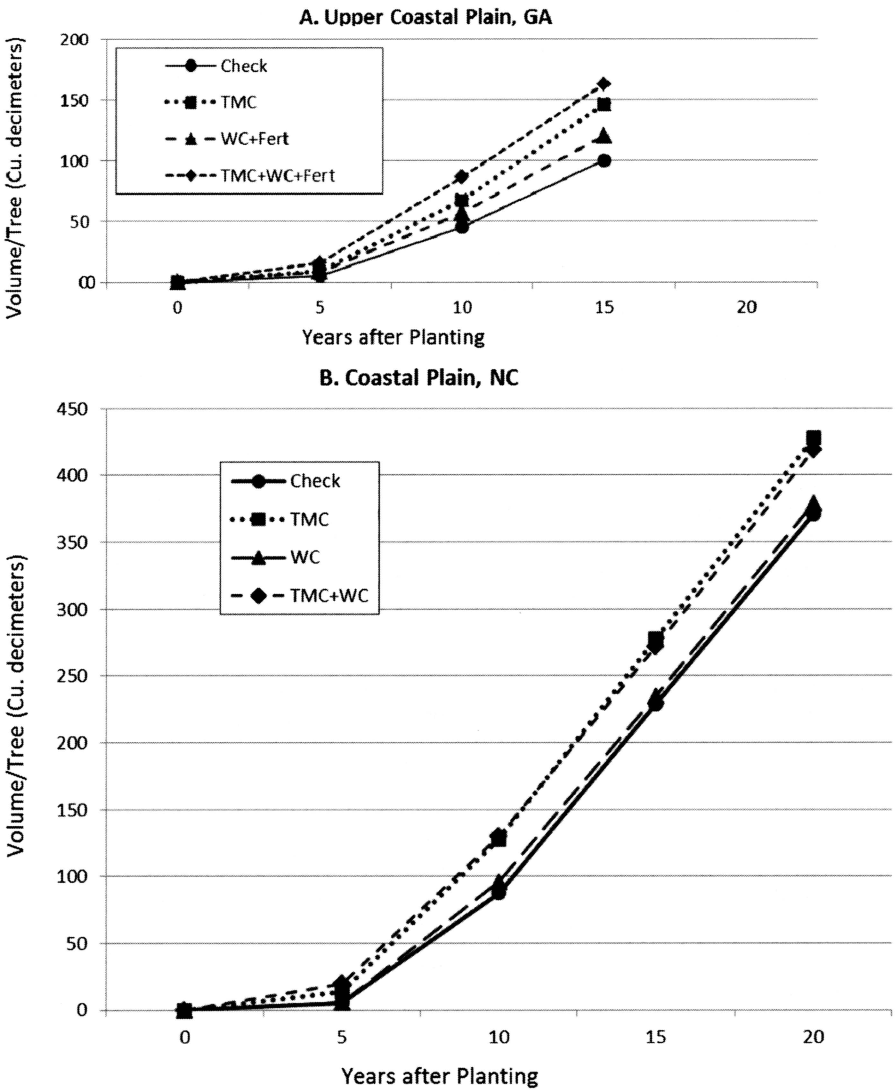

Fig. 1. Mean individual tree volumes for no treatment (Check), tip moth control (TMC), herbicide weed control (WC - North Carolina site), WC plus fertilizer (WC+Fert - Georgia site), tip moth control plus herbicide weed control (TMC+WC – North Carolina site), and tip moth control plus herbicide weed control plus fertilizer (TMC+WC+Fert – Georgia site) at ages 5, 10, and 15 at the Georgia location (A) and ages 5, 10, 15, and 20 at the North Carolina location (B).

North Carolina location responses – Ages 5 - 20. Average diameter (DBH) and height at the North Carolina location were increased by both weed control and tip moth control, but only the response to tip moth control was significant through year 20 (Table 3). Both DBH and height followed a pattern of response expected on a good site with 1174 trees/ha (475 trees/acre) in year 20, with declining response through year 20. However, average tree volume response from tip moth control continued to increase from 11.3 - 48.1 dm^3 (0.4 - 1.7 ft^3) per tree from year 5 to year 20 (Table 3, Fig. 1B). Volume per hectare response to tip moth control was 57.5 and 64.2 m^3/ha (822 and 917 ft^3/acre) (Table 4) for year 15 and 20, respectively, which equates to responses of 3.8 and 3.2 m^3/ha/yr (54.8 and 45.8 ft^3/acre/yr).

Management implications. The Georgia site had a relatively low expressed site index compared with the North Carolina site, as demonstrated by the large differential in average stem volumes between these two sites at age 15 (Fig. 1). Interestingly, the increase in average stem volume attributable to tip moth control was 39.2% at the Georgia site compared with 18.3% at the North Carolina site at age 15, but the actual volume gains from tip moth control were similar, 46 m^3/ha (657 ft^3/acre) at the Georgia site and 57.5 m^3/ha (822 ft^3/acre) at the North Carolina site (Table 4).

The North Carolina site had especially heavy tip moth infestation, which is typical of this region of the Southeast (Fettig and Berisford 1999b, McCravy et al. 2004). The heavy investment of time and chemicals used to control high tip moth infestations for 3 yrs in this study would be cost and environmentally prohibitive on an operational scale. However, controlling selected generations may provide sufficient reductions in damage to justify the cost of treatment (Fettig et al. 2000, Asaro et al. 2006). Clearly, a systemic insecticide applied at planting that would provide good control for up to 2 yrs would be a preferred treatment of tip moths in operational pine plantations in the South.

Table 3. Mean diameter (DBH), height, and individual tree volume by treatment at ages 5 and 20 for the North Carolina site.

	Year 5			Year 20		
Treatment	DBH (cm)	Height (m)	Volume (dm^3)	DBH (cm)	Height (m)	Volume (dm^3)
1. Check	5.8	3.7	5.7	22.4	19.7	370.7
2. TMC	9.1	5.2	14.2	23.6	20.5	427.3
3. WC	6.6	4.2	5.7	22.4	20.0	379.2
4. TMC+WC	9.9	5.6	19.8	23.4	20.5	418.8
Treatment Effect	Response Estimates[1,2]					
TMC	3.3**	1.4**	11.3**	1.3*	0.6*	48.1*
WC	0.8*	0.4*	2.8*	0.0 ns	0.2 ns	0.0 ns

[1]ns = not significantly different from no response at $P = 0.05$, * = significant at $P < 0.05$, ** = significant at $P < 0.01$.

[2]Average responses for main effects in terms of treatment numbers in NC are: TMC=(2 + 4 - 1-3)/2, WC=(3 + 4 - 1-2)/2.

Table 4. Mean volume per hectare at year 15 for the Georgia site and years 15 and 20 for the North Carolina site.

	Georgia	North Carolina	
	Year 15	Year 15	Year 20
Treatment	Avg. Volume[1] (m^3/ha)	Volume (m^3/ha)	Volume (m^3/ha)
1. Check	106.9	284.4	419.3
2. TMC	155.9	349.9	509.0
3. WC		299.1	453.1
4. WC+Fert	131.0		
5. TMC+WC+Fert	174.0		
6. TMC+WC	180.7	348.6	491.6
7. TMC+Fert	159.7		
Treatment Effect	**Volume Response Estimates (m^3/ha)[2,3,4]**		
TMC	46.0**	57.5**	64.2*
WC+Fert	21.1 ns	-	-
WC	19.5 ns	6.7 ns	8.2 ns
Fert	−1.4 ns	-	-
Thin	−39.6*	-	-

[1]Year 15 estimates for the GA site are based on the average of individual tree volumes using 1284 and 864 trees per hectare for unthinned and thinned blocks, respectively.
[2]ns = not significantly different from no response at $P = 0.05$, * = significant at $P < 0.05$, ** = significant at $P < 0.01$.
[3]Average responses for main effects in terms of treatment numbers for GA site are: TMC=(2 + 5 - 1-4)/2, WC+Fert=(4 + 5 - 2-1)/2, WC=(5 + 6 - 2-7)/2, Fert=(5 + 7 - 2-6)/2.
[4]Average responses for main effects in terms of treatment numbers for NC site are: TMC=(2 + 6 - 1-3)/2, WC=(3 + 6 - 1-2)/2.

Final differences in volume and product value at harvest among treatments in this study cannot be easily predicted because the differentials between checks and the "best" treatments are still increasing or are at least static after 15 and 20 years. Economic evaluations of this experiment should factor in quicker returns from thinnings, shorter rotation intervals and increased site productivity in comparison with stands receiving less intensive management. Increased growth rate and improved stem form from tip moth control will result in longer internodes, fewer knots and less compression wood, which may also increase product values from treated trees at harvest (Hedden and Clason 1980).

The differential in productivity due to intensive management which includes tip moth control will increase with higher infestations and large numbers of larvae per shoot. Protection of early shoot growth increased crown size and resulted in sizable long-term responses under intensive management regimes common at the time of the installation of this study. The potential infestation levels and potential gains from protection of improved genetic stock grown under intensive fertilization and vegetation management regimes will require additional studies to determine where intensive management, including tip moth control, will provide consistent economic benefits.

References Cited

Asaro, C., D. R. Carter and C. W. Berisford. 2006. Control of low-level Nantucket pine tip moth populations: A cost-benefit analysis. South. J. Appl. For. 30: 182-187.

Asaro, C., C. J. Fettig, K. W. McCravy, J. T. Nowak and C. W. Berisford. 2003. The Nantucket pine tip moth: A literature review with management implications. J. Entomol. Sci. 38: 1-40.

Baer, R. G. and C. W. Berisford. 1975. Species composition of pine tip moth, *Rhyacionia* spp. infestations in northeast Georgia. J. Georgia Entomol. Soc. 10: 64-67.

Beal, R. H. 1967. Heavy tip moth attacks reduce early growth of loblolly and shortleaf pines. USDA For. Serv. Res. Note 50-54, South. For. Exp. Stn., New Orleans, Louisiana. 3 p.

Beal, J. A., W. Haliburton and F. B. Knight. 1952. Forest insects of the Southeast with special reference to species occurring in the piedmont plateau of North Carolina. Duke Univ. School of Forestry, Bull. 14. 168 p.

Berisford, C. W. 1988. The Nantucket pine tip moth, Pg. 141-161. *In* Berryman, R. R. (ed.) Dynamics of forest insect populations. Plenum Publ. Corp.

Berisford, C. W. and H. M. Kulman. 1967. Infestation rate and damage by the Nantucket pine tip moth in six loblolly pine stand categories. For. Sci. 13: 428-438.

Berisford, C. W., J. F. Godbee Jr. and D. W. Ross. 1989. Impact of pine tip moth control, weed control and fertilizer on growth and form of loblolly pine, Pg. 130-136. *In* R.I. Alfaro and S.G. Glover (eds.), Insects Affecting Reforestation: Biology and Damage. Proc. IUFRO Working Group, Insects Affecting Reforestation *(S2.07-03)*. XVIII International Congress of Entomology, Vancouver, BC, Canada.

Berisford, C. W., C. G. Canalos, J. F. Godbee Jr. and H. O. Yates III. 1992. Occurrence and seasonal activity of pine tip moths in Georgia. Georgia Forestry Comm., Georgia Forest Res. Pap. 87, 11 p.

Burns, R. M. 1975. Tip moth control pays off. Forest Farmer 34: 13.

Cade, S. C. and R. L. Hedden. 1987. Growth impact of pine tip moth on loblolly pine plantations in the Ouachita mountains in Arkansas. South. J. Appl. For. 11: 128-133.

Fettig, C. J. and C. W. Berisford. 1999a. A comparison of three indices used for estimating Nantucket pine tip moth damage in the field. J. Entomol. Sci. 34: 203-209.

Fettig, C. J. and C. W. Berisford. 1999b. Nantucket pine tip moth phenology in eastern North Carolina and Virginia: Implications for effective timing of insecticide applications. South. J. Appl. For. 23: 30-38.

Fettig, C. J., K. W. McCravy and C. W. Berisford. 2000. Effects of Nantucket pine tip moth insecticide spray schedules on loblolly pine seedlings. South. J. Appl. For. 24: 106-111.

Foil, R. R., R. G. Merrifield and T. Hansbrough. 1961. Tip moth control on loblolly pine. Hill Farm. Facts Forestry II. La. State Univ. Hill Farm Exp. Stn. 5 p.

Gargiullo, P. M., C. W. Berisford and J. F. Godbee Jr. 1985. Prediction of optimal timing for chemical control of the Nantucket pine tip moth in the southeastern coastal plain. J. Econ. Entomol. 78: 148-154.

Graham, S. A. and L. G. Baumhofer. 1927. The pine tip moth in the Nebraska National Forest. J. Agric. Res. 35: 323-333.

Hansbrough, T. 1956. Growth of planted loblolly and slash pines in North Louisiana. Louisiana State Univ., For. Note 10. 2 p.

Hedden, R. L. 1998. Impact of Nantucket pine tip moth attack on loblolly pine: A south-wide summary, Pg. 569-573. *In* Waldrop, T. A. (ed.), Proc. of the Ninth Biennial Southern Silvicultural Conf., USDA For. Serv. Gen. Tech. Rep. SO-20, Southern Research Station, Asheville, NC.

Hedden, R. L. 2002. Impact of pine tip moth attack on loblolly pine, Pg. 1-7. *In* C. W. Berisford and D. M. Grosman (eds.). The Nantucket pine tip moth: old problems, new research. Proceedings of an informal conference. Entomol. Soc. Amer. Ann. Mtg., Dec. 12-16, 1999. USDA For. Serv. South. Res. Sta. Gen. Tech. Rep. SRS-51.

Hedden, R. L. and T. Clason. 1980. Nantucket pine tip moth impact on loblolly pine wood and product quality. Forest Res. Rep. 1979, LSU Agric. Exp. Sta., N. Louisiana. Hill Farm Exp. Sta. Homer, LA.

Hertel, G. D. and D. M. Benjamen. 1977. Intensity of site preparation influences on pine webworm and tip moth infestations of pine seedlings in North-Central Florida. Environ. Entomol. 6: 118-122.

Hood, M. W., R. L. Hedden and C. W. Berisford. 1988. Hazard rating forest sites for pine tip moth, *Rhyacionia* spp. in the upper Piedmont plateau. For. Sci. 34: 1083-1093.

Lashomb, J. H., A. L. Steinhauer and L. Douglass. 1978. Impact studies of Nantucket pine tip moth populations on loblolly pine. Environ. Entomol. 7: 910-912.

McCravy, K. W. and C. W. Berisford. 2001. Effects of vegetation control on parasitoids of the Nantucket pine tip moth, *Rhyacionia frustrana* (Lepidoptera: Tortricidae). Fla. Entomol. 84: 282-287.

McCravy, K. W., R. S. Cameron and C. W. Berisford. 2004. Variation in developmental synchrony of the Nantucket pine tip moth (Lepidoptera: Tortricidae) with implications for chemical control. J. Entomol. Sci. 39: 551-561.

Miller, W. E. and L. P. Wilson. 1964. Composition and diagnosis of pine tip moth infestations in the Southeast. J. Econ. Entomol. 57: 722-726.

Milliken, G. A. and D. E. Johnson. 1992. Analysis of Messy Data, Volume I: Designed Experiments. Chapman & Hall/CRC, New York. 473 p.

Nowak, J. T. and C. W. Berisford. 2000. Effects of intensive management practices on insect infestation levels and loblolly pine growth. J. Econ. Entomol. 93: 336-341.

Nowak, J. T., T. B. Harrington and C. W. Berisford. 2003. Nantucket pine tip moth development and population dynamics: influence of nitrogen fertilization and vegetation control. For. Sci. 49: 731-737.

Pienaar, L. V., T. Burgan and J. W. Rheny. 1987. Stem volume, taper and weight equations for site prepared loblolly pine plantations. Plantation Mgt. Res. Coop. Tech. Rep. No. 1987-1.

Powell, J. A. and W. E. Miller. 1978. Nearctic pine tip moths of the genus *Rhyacionia:* Biosystematic review (Lepidoptera: Tortricidae, Olethreutidae). USDA Agric. Handbook. No. 514. 51 p.

Ross, D. W., C. W. Berisford and J. F. Godbee Jr. 1990. Pine tip moth, *Rhyacionia* spp., response to herbaceous vegetation control in an intensively site-prepared loblolly pine plantation. For. Sci. 36: 1105-1118.

Schmidtling, R. C. 1984. Early intensive culture affects long term growth of loblolly pine trees. For. Sci. 30: 491493.

Terry, T. A., S. C. Cade and J. H. Hughes. 1984. Integrated pest management during plantation establishment (0-5 years), Pg. 97-114. *In* S. J. Branham and G. D. Hertel (eds.). Proc. Integrated Forest Pest Management Symposium. 19-21 June, 1984. Univ. Georgia Center for Continuing Education.

Wakeley, P. C. 1928. Preliminary observations on the pine tip moth, *Rhyacionia frustrana* (Comstock) on southern pines. Proc. 4th In. Congr. Entomol. Trans. 2: 865-868.

Warren, L. O. 1963. Nantucket pine tip moth infestations: severity of attacks as influenced by vegetative competition in pine stands. Arkansas Agric. Exp. Sta., Arkansas Farm. Res. Note. 1963: 4p.

Warren, L. O. 1964. Growth of pine trees protected from attack by Nantucket pine tip moth. Arkansas Farm Res. 13: 11.

White, M. N., D. L. Kulhavy and R. N. Connor. 1984. Nantucket pine tip moth (Lepidoptnera: Tortricidae) infestation rates related to site and stand characteristics in Nacogdoches Co., Texas. Environ. Entomol. 13: 1598-1601.

Williston, H. L. and S. J. Barras. 1977. Impact of tip moth injury on growth and yield of 16 year old loblolly and shortleaf pines. USDA For. Serv. Res. Note 50-221. South. For. Exp. Sta., New Orleans, Louisiana. 5 p.

Yates III, H. O. 1960. The Nantucket pine tip moth. A literature review. U.S. For. Serv. Southeast For. Exp. Stn. Stn. Paper No. 115. Asheville, NC, 19 p.

Young, J. D., C. W. Berisford and J. V. McHugh. 2006. Authorship of the Nantucket pine tip moth, *Rhyacionia frustrana* (Lepidoptera: Tortricidae). J. Kans. Entomol. Soc. 79: 378-379.