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Effects of fertilization and herbicides on growth of young loblolly pine and infestations of Nantucket pine tip moth (Lepidoptera: Tortricidae)

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Abstract A 2-year-old pine plantation was selected to receive treatments of fertilizers and herbicides to evaluate effects on Nantucket pine tip moth infestations and the tree growth parameters of height, diameter and volume increment. Nitrogen and phosphorus fertilizers, and hexazinone and sulfometuron methyl herbicides were used in creating six treatments: (i) control; (ii) phosphorus; (iii) nitrogen and phosphorus; (iv) phosphorus and herbicide; (v) nitrogen, phosphorus and herbicide; and (vi) herbicide. Treatments were applied in 1987 and 1988. In 1987, trees treated with nitrogen, phosphorus and herbicide had significantly greater height, diameter and volume growth than trees not receiving fertilizer treatments, but did not have significantly higher tip moth infestations than control trees. Treatments receiving phosphorus only had much lower tip moth infestation rates than other treatments except nitrogen and phosphorus. In 1988, tip moth infestations were uniformly low, with no differences in treatment effects observed.

Key words fertilizers, herbicides, infestation rates, Nantucket pine tip moth, nitrogen, phosphorus

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Introduction

The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae) (NPTM) is an important pine regeneration insect in the eastern and southern United States. Larval feeding in the meristematic tissue of young pines causes significant damage, particularly in areas where forest regeneration favors its proliferation (Yates *et al*., 1981). Southeastern industrial forestry, to maximize production of wood and fiber, currently emphasizes establishment of large, homogeneous pine plantations. Given abundant food supply and ideal breeding conditions, NPTM can rapidly increase, causing both economic and aesthetic damage. Increased damage by tip moth following vegetation control may result from improved suitability of pine tissue for larvae and a greater abundance of tip moth feeding sites (Ross & Berisford, 1990).

Environmental and physiological factors influencing NPTM include soil texture affecting the growth of the host and influencing soil moisture relations, rooting characteristics and tree growth (Pritchett & Fisher, 1979). Meeker and Kulhavy (1992) found that NPTM infestation rates increased with percentage of silt-sized particles in the soil. NPTM infestation rates increase as site preparation intensity increases and levels of competing vegetation and overstory decrease (Berisford & Kulman, 1967; Hertel & Benjamin, 1977; White *et al*., 1984; Zutter *et al*., 1986; Hood *et al*., 1988; Lantagne & Burger, 1988; Nowak & Berisford, 2000). Intensive forest management practices that improve tree growth, such as weed control and fertilization, have been shown to exacerbate its damage

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(Ross & Berisford, 1990; Ross *et al*., 1990; Sun *et al*., 1998). However, McCravy and Berisford (2001) showed significantly lower tip moth damage in plots with vegetation control than in untreated plots. According to Miller and Stephen (1983), competing herbaceous and woody vegetation provides food and shelter for NPTM predators and parasites.

Pritchett and Smith (1972) observed little change in tip moth infestation on trees fertilized with nitrogen. Applications of phosphorus, however, resulted in a significant tip moth reduction, with potassium reducing tip moth levels even further. Tiarks and Haywood (1986) in a study measuring effects of fertilization and vegetation control on loblolly pine, *Pinus taeda* L., observed uniform tip moth damage across all treatments, but NPTM infestations were not quantified. Meeker and Kulhavy (1992) found a negative correlation between phosphorus levels in soil and foliage, and NPTM infestation rates, with increasing levels of phosphorus associated with decreasing infestation rates. Reasons for this are unknown, but increased vigor may serve to bolster the trees' natural defenses, particularly resin production (Berisford, 1987). Resin production is an important defense against NPTM infestation (Yates, 1964; Berisford, 1987), although larvae are able to tolerate some resin flow by secreting a substance that speeds crystallization of resin in loblolly and shortleaf pines (Yates, 1962).

Fertilization of newly established pine plantations is not recommended without herbicide application (Pritchett & Smith, 1979, Funderburg & Mills, 1998). Herbaceous and woody competitors may get more of the fertilizer than the pines, leading to increased competition for water and nutrients.

Herbicides, including sulfometuron methyl (Oust®) and hexazinone (Velpar®-L) are commonly used to reduce competing herbaceous vegetation in loblolly pine plantations (Cantrell *et al*., 1985; Michael, 1985; Creighton *et al*., 1986; Yeiser & Boyd, 1989; Yeiser & Rhodenbaugh, 1994; Kulhavy *et al*., 2004). Ross *et al*. (1990) documented that percent infested trees and percent infested shoot tips were significantly higher in the banded and broadcast treated plots that in check plots during the third tip moth generation. Objectives of this study were to examine effects of fertilization with and without competing vegetation control on tree growth parameters and Nantucket pine tip moth infestation levels.

Materials and methods

Plot establishment

Sixteen 0.3 hectare plots were established in February 1987 on a 2-year-old loblolly pine plantation located 1 km north of Etoile, Texas, USA, in Nacogdoches County on County Road 445. The area was industrial forest land and was part of a recently regenerated clearcut several square km in area. Each plot consisted of 20 rows of 22 trees planted on a 1.3 m × 1.2 m spacing. Buffer zones 20 m wide were left between plots.

Treatments

General treatments assigned at random among the 16 plots were control (no treatment), fertilizer, fertilizer plus herbicide, and herbicide only. Plots receiving fertilizer were split in half by row number and one of two fertilizer treatments assigned to each split plot. This resulted in six treatments: (i) control (C); (ii) phosphorus only (P); (iii) nitrogen plus phosphorus (NP); (iv) phosphorus and herbicide (PH); (v) nitrogen, phosphorus and herbicide (NPH); and (vi) herbicide only (H). Treatments were replicated four times. The first fertilizer treatment was an application of concentrated superphosphate fertilizer (0-46-0) at a rate of 56 kg/ha elemental phosphorus (P). The second treatment consisted of the first treatment plus ammonium nitrate (34-0-0) at a rate of 225 kg/ha elemental nitrogen (N). Fertilizer was applied by hand, with measured amounts corresponding to the rate per hectare evenly distributed within a circle of 0.5 m radius around each tree. Fertilizer applications were completed May 1, 1987 and March 25, 1989.

Herbicide application was made June 3, 1987 and May 18, 1988 using a tractor with a boom sprayer. Herbicide treatments combined sulfometuron methyl (Oust®) and hexazinone (Velpar®-L) at rates of 210.5 g/ha and 0.4 L/ha Velpar®-L in 1987 at rates of 280.7 g/ha and 1.2 L/ha Velpar®-L in 1988.

Site description

Plots were established on a Kullit series soil (fine-loamy, siliceous, thermic Aquic Paleudalt), moderately well-drained, with moderately slow permeability; and high water-holding capacity. The area was relatively flat, with slopes ranging from 1%–3%. Site index for pine (age 50) is 90 (27.4 m) (Dolezel, 1980). Soil uniformity was verified on each plot by soil sampling. Each plot was subdivided into four quadrants, with samples taken at depths of 15 and 50 cm in the center of each quadrant. Textural analysis was performed using the Bouyoucos method. For soil nutrient analysis, composite samples were made at each depth from the four sampling points on each plot, or the two sampling points on the split plot. Total nitrogen was determined by the Micro-Kjeldahl method. Emission spectroscopy was used for measurement of phosphorus.

Foliage sampling for nutrient analysis

After plot establishment in late February 1987, three sample trees from each row in each plot were selected at random for foliar nutrient sampling. The trees were numbered and flagged, and a minimum of 15 fascicles of mature, fully developed needles collected from the first flush of the previous season's growth. Foliar sampling was repeated prior to the 1988 growing season. Needles were combined in composite samples of 10 adjacent sample trees per sample, resulting in six composite samples per plot. Foliar macronutrient and micronutrient concentrations were analyzed at the Department of Agriculture laboratory, Stephen F. Austin State University. Total nitrogen was determined by the Micro-Kjeldahl method. Emission spectroscopy was used for measurement of phosphorus.

Tree growth and data analysis

Of the three trees in each row chosen for foliar sampling, one was selected for measurement and monitoring of height, basal diameter, and NPTM infestation (20 trees per plot). Measurements were repeated at the end of the growing seasons in 1987 and 1988 to evaluate treatments.

Nantucket pine tip moth infestation rates

Nantucket pine tip moth infestation rates were measured at the end of October 1987, and again in October 1988. Whole tree infestation rates were calculated as a ratio of total apparently infested tips to total tips.

Average pre-treatment height of P-treatment trees (61.92 cm) was statistically greater than control, NP and H trees, with mean heights of 50.49 cm, 48.62 cm and 49.54 cm respectively. To test whether or not this difference influenced post-treatment NPTM infestation rates, sample trees were stratified into pre-treatment height classes of 0−40 cm, 41−75 cm and > 75 cm.

To test the possibility of competing vegetation effects, trees were divided into two groups: those below mean height (118 cm) and those above mean height. NPTM infestations on trees below mean height should have been more influenced by competing vegetation than on trees above mean height. Data were analyzed using one-way analysis of variance with Duncan Multiple Range Test ($P < 0.05$).

Results

Tree growth

Treatments of fertilizer and herbicide in 1987 were effective, with sample tree growth as expected. Mean height growth ranged from 60.0 cm for herbicide trees to 75.1 for NPH trees (Table 1). Mean diameter growth ranged from 0.65 cm in control to 1.13 cm for NPH trees (Table 1). Mean overall volume growth in 1987 ranged from 130.0 cm^3 to 278.8 cm^3 for NPH (Table 1). NPH and PH treatments had significantly ($P < 0.05$) greater volume growth than control. Fertilizer treatments were moderately effective in 1988, but herbicide treatments were practically ineffective. Oust® and Velpar®-L are soil active, but require adequate soil moisture to be effective. Unusually hot and dry conditions followed the application. Mean 1988 height growth ranged from 114.0 cm in control trees to 129.5 in NPH trees (Table 1). Diameter growth ranged from 2.45 cm for H treatment trees to 2.84 cm in P trees (Table 1). Mean volume growth in 1988 (Table 1) ranged from 1 407.01 cm^3 in the control to 2 077.23 cm^3 in NPH. NPH trees had significantly greater volume growth ($P < 0.05$) in 1988 than control or H treatments. Control trees had the least height, diameter and volume growth in both growing seasons. Ranking trees by treatment according to volume growth over the two seasons (from Table 1) shows NPH was significantly larger than H or control. Adding nitrogen or phosphorus had no statistically significant effect on tree growth, but was observed to result in increased weed growth in plots with no herbicide treatment.

Analysis of post-treatment infestation rates within the three pre-treatment tree height strata show P trees with NPTM infestation rates significantly lower than control and NPH at 0−40 cm and lower than H at 41−75 cm (Table 2). These results strongly suggest a treatment effect in 1987.

Nantucket pine tip moth infestation

NPTM infestation rates among sample trees grouped by treatment showed no difference between NPH, control, H and PH treatments, with mean infestation rates of 11.03%, 10.03%, 9.97% and 8.53 %, respectively (Table 3). P and NP treatments, with mean infestation rates of 5.84% and 6.74% had lower infestation rates than the control group. P was significantly lower than control, NPH, and H treatments; and NP trees were significantly lower than NPH trees. No significant differences were found in 1988 (Table 3) with mean infestations ranging from 1.78% in P trees to 3.32 % in H trees.

For trees below mean height, NP trees had the lowest mean infestation rate at 5.22% (Table 4). This was significantly lower than the control at 10.94% or NPH at 14.14%. P trees, with a mean infestation rate of 6.29%, also had significantly lower infestation rates than NPH trees. The

Table 1 Mean height growth (cm), basal diameter growth (cm), and volume growth (cm^3) of sample trees grouped by treatment.

Treatment	Height growth (cm) 1987 (SD)	Height growth (cm) 1988 (SD)	Height growth (cm) two seasons (SD)
Control	60.9 a† (20.40)	114.0 a (27.5)	174.9 a (39.4)
P	68.1 ab (23.20)	118.9 ab (23.3)	187.0 ab (40.1)
NP	70.4 ab (30.64)	123.2 ab (30.0)	193.6 ab (54.8)
PH	69.0 ab (27.90)	123.9 ab (24.8)	192.9 ab (45.4)
NPH	75.1 b (23.20)	129.5 b (30.6)	204.7 b (45.4)
H	59.9 a (25.40)	123.7 ab (34.8)	183.6 a (52.5)
Treatment	**Diameter growth (cm) 1987 (SD)**	**Diameter growth (cm) 1988 (SD)**	**Diameter growth (cm) two seasons (SD)**
Control	0.65 a† (0.32)	2.64 ab (0.69)	3.29 a (0.86)
P	0.68 a (0.42)	2.84 b (0.84)	3.52 ab (1.08)
NP	0.67 a (0.40)	2.70 ab (0.92)	3.37 a (1.13)
PH	0.97 bc (0.54)	2.74 ab (0.79)	3.71 ab (1.07)
NPH	1.13 c (0.66)	2.78 ab (0.81)	3.91 b (1.15)
H	0.82 ab (0.52)	2.46 a (0.74)	3.28 a (1.05)
Treatment	**Volume growth (cm^3) 1987 (SD)**	**Volume growth (cm^3) 1988 (SD)**	**Volume growth (cm^3) two seasons (SD)**
Control	129.94 a† (121.16)	1 407.01 a (928.39)	1 536.95 a (1 033.49)
P	200.54 ab (129.04)	1 886.20 ab (1 265.86)	2 086.74 ab (1 434.14)
NP	181.37 ab (213.38)	1 710.39 ab (1 406.70)	1 891.76 ab (1 592.60)
PH	242.69 b (278.00)	1 870.71 ab (1 362.50)	2 113.40 ab (1 605.33)
NPH	278.80 b (259.62)	2 077.23 b (1 187.15)	2 356.03 b (1 605.33)
H	194.06 ab (206.59)	1 541.26 a (1 187.15)	1 735.32 a (1 368.65)

†Within columns, means followed by the same letter are not significantly different ($P < 0.05$) using Duncan's Multiple Range Test; SD, standard deviation; P, phosphorus only; NP, nitrogen plus phosphorus; PH, phosphorus and herbicide; NPH, nitrogen, phosphorus and herbicide; H, herbicide only.

Table 2 Mean Nantucket pine tip moth infestation rates between sample trees grouped by treatment and stratified by pre-treatment height classes in 1987.

Treatment	Height 0–40 cm No.	Height 0–40 cm Infestation (%) (SD)	Height 41–75 cm No.	Height 41–75 cm Infestation (%) (SD)	Height > 75 cm No.	Height > 75 cm Infestation (%) (SD)
Control	20	13.19 b† (14.75)	46	9.04 ab (5.04)	8	7.82 a (5.06)
P	8	1.35 a (2.59)	20	7.36 a (8.15)	12	6.30 a (5.40)
NP	14	4.66 a (9.90)	20	8.83 ab (6.04)	3	2.56 a (3.11)
PH	11	7.88 ab (9.43)	18	8.39 ab (5.93)	8	9.75 a (6.37)
NPH	8	14.19 b (8.01)	25	11.23 ab (8.10)	6	6.00 a (2.76)
H	26	7.45 ab (9.72)	38	11.98 b (9.08)	10	8.89 a (6.07)

†Within columns, means followed by the same letter are not significantly different ($P < 0.05$) using Duncan's Multiple Range Test; SD, standard deviation; P, phosphorus only; NP, nitrogen plus phosphorus; PH, phosphorus and herbicide; NPH, nitrogen, phosphorus and herbicide; H, herbicide only.

Table 3 Nantucket pine tip moth whole-tree infestation (Inf) rates for sample trees grouped by treatment, 1987−1988.

Treatment	No. of trees	Inf (%) 1987 (SD)	Inf (%) 1988 (SD)
Control	74	10.03 bc† (8.87)	3.31 a (4.95)
P	40	5.84 a (6.87)	1.78 a (2.74)
NP	37	6.74 ab (7.79)	2.49 a (3.54)
PH	37	8.53 b (7.05)	2.06 a (3.43)
NPH	39	11.03 c (7.77)	2.62 a (3.60)
H	74	9.97 bc (9.12)	3.32 a (5.02)

†Within columns, means followed by the same letter are not significantly different ($P < 0.05$) using Duncan's multiple range test; SD, standard deviation; P, phosphorus only; NP, nitrogen plus phosphorus; PH, phosphorus and herbicide; NPH, nitrogen, phosphorus and herbicide; H, herbicide only.

only difference between trees with the lower infestations (NP) and the highest (NPH) is vegetation control. NP supplanted P trees as the treatment with the overall lowest infestation rates in trees below mean height.

In trees above mean height, H had a higher infestation rate than P, with mean infestation rates of 9.93% and 5.51%, respectively (Table 4). No other statistically significant differences were found. Infestation rates decreased with height for all treatments except NP, which increased from 5.22% to 8.35%.

Infestation rates were uniformly low for 1988, ranging from 1.78% in P trees to 3.22% in H treatments (Table 2). No groups were significantly different. Stratification of trees into discrete height classes clearly shows the pattern of tree height interacting with NPTM infestation in both years (Table 5). Although statistical analyses were precluded by low sample size in the 200−300 cm class in 1987 and the 0−100 cm class in 1988, such a relationship has been noted by a number of researchers (Berisford, 1987).

Soil and foliar sampling

No significant differences were found in soil texture or nutrient content among samples. Pre-fertilizer foliar N and P were not different according to treatment (Table 6). Significant differences were seen in post-application samples, but could not be attributed to treatment effect as control trees were in the same category as fertilized trees.

Table 4 1987 mean Nantucket pine tip moth infestation rates in sample trees below and above mean height of 118 cm grouped by treatment.

Treatment	Below 118 cm		Above 118 cm	
	No. of trees	Infestation (%) (SD)	No. of trees	Infestation (%) (SD)
Control	47	10.94 b† (10.68)	27	8.43 ab (3.85)
P	17	6.29 ab (8.79)	23	5.51 a (5.21)
NP	19	5.22 a (9.13)	18	8.35 ab (5.92)
PH	16	9.29 ab (8.11)	21	7.95 ab (6.27)
NPH	14	14.14 b (8.70)	25	9.29 ab (6.77)
H	45	9.99 ab (9.50)	29	9.93 b (8.56)

†Within columns, means followed by the same letter are not significantly different ($P < 0.05$) using Duncan's Multiple Range Test; P, phosphorus only; NP, nitrogen plus phosphorus; PH, phosphorus and herbicide; NPH, nitrogen, phosphorus and herbicide; H, herbicide only.

Table 5 Mean Nantucket pine tip moth infestation rates by height class for 1987 and 1988.

Height (cm)	1987		1988	
	No. of trees	Infestation (%) (SD)	No. of trees	Infestation (%) (SD)
0−100	96	9.06 (10.55)	5	11.67 (9.11)
100−200	200	9.05 (7.15)	73	5.73 (6.16)
200−300	5	5.74 (3.18)	179	1.72 (2.32)
300+	0	NA	44	1.11 (1.44)

Table 6 Pre- and post-fertilizer treatment foliar nitrogen and phosphorus concentrations (%) by treatment category, 1987.

Treatment	Pre-N (SD)	Pre-P (SD)	Post-N (SD)	Post-P (SD)
Control	0.79 a[†] (0.07)	0.08 a (0.01)	1.20 b (0.08)	0.088 ab (0.01)
P	0.84 a (0.28)	0.08 a (0.02)	1.17 ab (0.07)	0.093 b (0.01)
NP	0.76 a (0.07)	0.07 a (0.02)	1.16 ab (0.06)	0.091 b (0.01)
PH	0.78 a (0.08)	0.07 a (0.01)	1.12 a (0.09)	0.091 b (0.01)
NPH	0.80 a (0.06)	0.07 a (0.01)	1.19 ab (0.10)	0.091 b (0.01)
H	0.79 a (0.08)	0.07 a (0.01)	1.15 ab (0.08)	0.084 a (0.01)

[†]Within columns, means followed by the same letter are not significantly different ($P < 0.05$) using Duncan's Multiple Range Test; P, phosphorus only; NP, nitrogen plus phosphorus; PH, phosphorus and herbicide; NPH, nitrogen, phosphorus and herbicide; H, herbicide only.

Discussion

Stark (1964) hypothesized that increases in foliar nutrient concentrations after fertilization might have a direct toxic effect or repellent effect on some insects, particularly those adapted to feeding on tissues low in nutrients. Meeker and Kulhavy (1992) found that NPTM infestation rates on three different sites in east Texas decreased as foliar phosphorus levels increased. Such a conclusion cannot be drawn from the data from this experiment. Post-treatment foliar phosphorus levels are almost identical for P and NPH treatments (Table 6), while having the lowest and highest infestation rates (Table 3), respectively.

Competing vegetation has long been observed as an important factor in NPTM infestation rates (Wakeley, 1928; Yates, 1960; Berisford & Kulman, 1967; Miller & Stephen, 1983), with low levels of vegetation associated with higher tip moth infestation rates. Competing vegetation reduces growth, impedes oviposition by making the host tree less accessible, and harbors parasites and predators (Miller & Stephen, 1983). Fertilization in conjunction with weed control should result in a more desirable host by increasing succulent growth and reducing competing vegetation. Only PH and NPH treatments had volume growth significantly higher than control in 1987 (Table 1). P and NP treatments had moderate volume growth, but not significantly different from any other treatment. Although levels of competing vegetation were not quantified, herbaceous vegetation around P and NP trees was noticeably darker green in color and greater in quantity than in other treatments. Lower overall volume growth than in fertilizer-herbicide combinations suggests that some quantity of fertilizer was usurped by the herbaceous vegetation. Enhancing competing vegetation was at least partly responsible for lower NPTM infestation rates caused by fertilizer-only treatments. Tip moth damage in relation to forest regeneration practices displays an inverse relationship between damage and amount of competing vegetation (Berisford & Kulman, 1967; White *et al*., 1984; Hood *et al*., 1988; Ross *et al*., 1990; Sun *et al*., 1998, 2000). Miller and Stephen (1983) and Nowak and Berisford (2000) found no differences in damage levels between herbicide-treated and untreated plots, but greater temporal variation in tip moth damage levels in the treated plots. They found generally lower infestation rates in treated compared to untreated plots at low tip moth densities.

Improved host vigor, if defined simply as increased stemwood production, cannot explain differences in NPTM infestation rates. Infestation rates were the same for the least vigorous (control), intermediate (H) and the vigorous (NPH) trees (Tables 1 & 3). Lowest infestation rates occurred on fertilized trees with intermediate growth (P and NP). An effect of simultaneously increasing the trees' metabolic rate and competition for moisture is slightly increased moisture stress. According to Lorio (1985) and Lorio and Sommers (1986), moderate moisture stress reduces growth in loblolly pine, but not photosynthesis and translocation of photosynthates. Differentiation processes such as oleoresin production, the trees' major internal defense mechanism, are favored by this situation. Fertilization alone may have resulted in a slower growing but more resistant host than fertilizer plus herbicide. Enhanced competing vegetation increased external barriers to NPTM infestation while also improving internal defenses. Fertilization with weed control produced a faster growing host with fewer external NPTM barriers, and lower internal resistance.

Fertilization of southern pines has been shown to increase susceptibility to Nantucket pine tip moth (Herms, 2002). This is by decreasing the production of secondary metabolite compounds responsible for the chemical defenses against insects. Fertilization of loblolly pine, *Pinus taeda*, increased growth and decreased concentrations of foliar phenolic compounds, resulting in decreasing resistance to the Nantucket pine tip moth (Herms, 2002). Nowak *et al*. (2003) and Nowak and Berisford (2000) show that tip moth populations are not necessarily increased or decreased by intensive management practices, but can be less stable due to these practices following treatments of nitrogen fertilizer, herbicides, herbicides and fertilizers and controls.

Differences in 1987 NPTM infestation rates were not related either to phosphorus concentrations in foliage or volume increment alone. P trees and NPH trees had the same levels of P in the needles before and after treatment (Table 6), but had the lowest and highest infestation rates, respectively. Control trees, H trees, and NPH trees had the lowest, intermediate and highest volume growth, respectively, but not significantly different infestation rates.

Two main treatment effects on the trees and their immediate environment explain differences in 1987 infestation rates. Fertilization without weed control resulted in an increase in volume and vigor of competing herbaceous vegetation around the trees. Competing vegetation is a known factor in influencing NPTM infestation rates (Wakeley, 1928; Yates, 1960; Miller & Stephen, 1983; Berisford, 1987), with higher levels associated with lower infestations. The effect was especially pronounced in trees below mean height (Table 4), which would be the most affected by competing vegetation. For trees below mean height, mean infestation rates were lowest for NP trees at 5.22% and highest for NPH trees at 14.14%. Herbicide was the only difference between the two treatments.

It is important to note that NPTM infestation rates were relatively low across all treatments, and that trees receiving both fertilizers and herbicides did not have significantly more tip moth damage than controls (Table 3). At the same time, height, diameter and overall volume increment of NPH trees were significantly higher than controls (Table 1). This may indicate that benefits of such cultural treatments may outweigh increased risk of tip moth damage when tip moth populations are low.

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References

Berisford, C.W. and Kulman, H.M. (1967) Infestation rates and damage by the Nantucket pine tip moth in six loblolly pine categories. *Forest Science*, 13, 428−438.

Berisford, C.W. (1987) The Nantucket pine tip moth. *Forest Insect Outbreaks: Patterns, Causes and Management Strategies* (ed. A.A. Berryman), Chapter 6. Plenum Publishing Corporation, New York, NY USA.

Cantrell, R.L., Minogue, P.J., Metcalfe, C.S. and Zutter, B.R. (1985) Silvicultural herbicide uses. *A Guide to Silvicultural Herbicide Use in the Southern United States* (ed. R.L. Cantrell), pp. 1−14. Auburn University, Auburn, Alabama, USA.

Creighton, J.L., Glover, G.R. and Zutter, B.R. (1986) Loblolly pine growth response to herbaceous weed control − a summary of 15 studies. *Proceedings of the Southern Weed Society*, 39, 193.

Dolezel, R. (1980) *Soil Survey of Nacogdoches County, Texas*. U. S. Department of Agriculture Soil Conservation Service, Washington D.C. USA.

Funderburg, E.R. and Mills, R.H. (1998) *Fertilizing pine forests in Louisiana*. Louisiana Cooperative Extension Service Publication 2691, Baton Rouge, Louisiana USA. 4 pp.

Herms, D.A. (2002) Effects of fertilization on insect resistance of woody ornamental plants: reassessing an entrenched paradigm. *Environmental Entomology*, 31, 923−933.

Hertel, G.D. and Benjamin, D.M. (1977) Intensity of site preparation influences on pine webworm and tipmoth infestations on pine seedlings in north central Florida. *Environmental Entomology*, 6, 118−122.

Hood, W.M., Hedden, R.L. and Berisford, C.W. (1988) Hazard rating forest sites for pine tip moth, *Rhyacionia* spp. in the upper Piedmont Plateau. *Forest Science*, 34, 1083−1093.

Kulhavy, D.L., Yeiser, J.L. and Smith, L.A. (2004) Nantucket pine tip moth control and loblolly pine growth in intensive pine culture: two-year results. *Proceedings of the 12th Biennial Southern Silvicultural Research Conference* (ed. K. Conner), pp. 147−149. Gen. Tech. Rep. SRS-71, Asheville, NC, U. S. Department of Agriculture, Forest Service, Southern Research Station, 594 pp.

Lantagne, D.O. and Burger, J.A. (1988) Effects of site preparation intensity on the early growth of loblolly pine (*Pinus taeda* L.) and the incidence of pine tip moth (*Rhyacionia* spp.). *New Forest*, 2, 219−229.

Lorio, P.L.Jr. (1985) Growth-differentiation balance: a basis for understanding southern pine beetle-tree interactions. *Forest Ecology and Management*, 14, 259−273.

Lorio, P.L.Jr. and Sommers, R.A. (1986) Evidence of competition for photosynthates between growth processes and oleoresin synthesis in *Pinus taeda* L. *Tree Physiology*, 2, 301−306.

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

Meeker, J.R. and Kulhavy, D.L. (1992) Pine tip moth (Lepidoptera: Tortricidae) infestation rates as influenced by site and stand characteristics in loblolly pine plantations in east Texas. *Environmental Entomology*, 21, 534−541.

Michael, J.L. (1985) Growth of loblolly pine treated with Hexazinone, Sulfometuron methyl and metsulfuron methyl for herbaceous weed control. *Southern Journal of Applied Forestry*, 9, 20−26.

Miller, F.D.Jr. and Stephen, F.M. (1983) Effects of competing vegetation on Nantucket pine tip moth (Lepidoptera: Tortricidae) populations in loblolly pine plantations in Arkansas. *Environmental Entomology*, 12, 101−105.

Nowak, J.T. and Berisford, C.W. (2000) Effects of intensive management practices on insect infestation levels and loblolly pine growth. *Journal of Economic Entomology*, 93, 336−341.

Nowak, J.T., Harrington, T.B. and Berisford, C.W. (2003) Nantucket pine tip moth development and population dynamics: Influence of nitrogen fertilization and vegetation control. *Forest Science*, 49, 731−737.

Pritchertt, W.L. and Fischer, R.F. (1979) *Properties and Manage ment of Forest Soils*, 2nd ed. John Wiley and Sons, New York.

Pritchett, W.L. and Smith, W.H. (1972) Fertilizer response in young pine plantations. *Soil Science Society of America Proceedings*, 36, 660−663.

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

Ross, D.W. and Berisford, C.W. (1990) Nantucket pine tip moth response to water nutrient status of loblolly pine. *Forest Science*, 36, 719−733.

Stark, R.W. (1964) Recent trends in forest entomology. *Annual Review of Entomology*, 10, 303−324.

Sun, J., Kulhavy, D.L. and Yan, S. (1998) Prediction models of Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lep., Tortricidae) infestation using soil and tree factors. *Journal of Applied Entomology*, 122, 1−3.

Sun, J.H., Kulhavy, D.L. and Roques, A. (2000) Effects of fertilizer and herbicide application on Nantucket pine tip moth infestation (Lep., Tortricidae). *Journal of Applied Entomology*, 124, 191−195.

Tiarks, A.E. and Haywood, J.D. (1986) *Pinus taeda* L. response to fertilization, herbaceous plant control, and woody plant control. *Forest Ecology and Management*, 14, 103−112.

Wakeley, P.C. (1928) Preliminary observations on the pine tip moth (*Rhyacionia frustrana* Comst.) on southern pine. *Transactions 4th International Congress of Entomology*, 2, 865−868.

White, M.R., Kulhavy, D.L. and Conner, R.N. (1984) Nantucket pine tip moth (Lepidoptera: Tortricidae) infestation rates related to site and stand characteristics in Nacogdoches County, Texas. *Environmental Entomology*, 13, 1598−1601.

Yates, H.O. (1960) The Nantucket pine tip moth *Rhyacionia frustrana* (Comstock), A literature review. U. S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station Paper No. 115, Asheville, North Carolina USA. 18 pp.

Yates, H.O. (1962) Influence of tip moth larvae on oleoresin crystallization of southern pines. U. S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station Res. Note 174, Asheville, North Carolina USA. 2 pp.

Yates, H.O., Overgaard, N.A. and Koerber, T.W. (1981) Nantucket pine tip moth. U. S. Department of Agriculture, Forest Service, Insect and Disease Leaflet. 70, pp.7.

Yeiser, J.L. and Boyd, J.W. (1989) Control of competitors yields two-year seedlings response. *Proceedings of the Southern Weed Science Society*, 42, 181−188.

Yeiser, J.L. and Rhodenbaugh, E.J. (1994) Early survival and growth of loblolly pine seedlings treated with sulfometuron or Hexazinone plus Sulfometuron in southwest Arkansas. *Tree Planters's Notes*, 45, 116−120.

Zutter, B.R., Glover, G.R. and Gerstad, D.H. (1986) Effects of herbaceous weed control using herbicides on a young loblolly pine plantation. *Forest Science*, 32, 882−899.

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