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David L. Kulhavy
dkulhavy@sfasu.edu

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Effects of fertilizer and herbicide application on Nantucket pine tip moth infestation (Lep., Tortricidae)

J. H. Sun[1], D. L. Kulhavy[2] and A. Roques[3]
[1]Institute of Geographical Sciences, Academy of Sciences, Beijing, China; [2]College of Forestry, Stephen F. Austin State University, Nacogdoches, USA; [3]INRA-CRF, Orleans, Zoologie Forestiere, Ardon, Olivet, France

Abstract: A study of fertilizer and herbicide effects on Nantucket pine tip moth (NPTM), *Rhyacionia frustrana* (Comstock) infestations was conducted in loblolly pine (*Pinus taeda* L.) plantations in Nacogdoches Co., Texas, from 1988 to 1989. Both fertilizer and herbicide applications had effects on NPTM infestation level, pupal weight and host tree oleoresin production. Nitrogen fertilization increased infestation levels; whereas, phosphorus applications tends to decrease infestation rate. Herbicide treatment had a negative effect on NPTM infestations possibly because of decreased moisture stress and increased tree vigour. This is in contrast to general observations of increased NPTM infestations associated with reducing competing vegetation. Fertilizer application alone did not significantly improve pine growth due to competing vegetation. A combination of fertilizer and herbicide achieved the best growth.

1 Introduction

The Nantucket pine tip moth (NPTM), *Rhyacionia frustrana* (Comstock), is an important pine insect pest in eastern and southern United States. Localized populations also exist in California, New Mexico, and Arizona (BERISFORD, 1988). Larvae feed on buds and new shoots, causing serious damage to young pines, particularly in seed orchards, nurseries, and Christmas tree plantations. Repeated attacks may result in limited height growth, stem deformation, loss in wood quality, bushy appearance, reduced cone crop, lower aesthetic value and even tree mortality (YATES et al., 1981). Tip moth damage is most severe on seedlings and saplings usually under 5 years of age and less than 7 m in height (FOX and KING, 1963).

NPTM has two to five generations annually, depending on the climate. Most areas of Texas have four generations per year with a fifth generation during the most favourable seasons (LEWIS, 1976). Generations can usually be distinguished, but considerable overlap may occur even in areas with as few as three annual generations (BERISFORD et al., 1989).

Effects of fertilization and herbicide applications on insect populations and damage have been studied for several decades with contradictory results. MATTSON (1980) postulated that variation in larva populations of many insects is directly related to changes in nitrogen levels in host plants. PRICHETT and SMITH (1972) observed little changes in infestation of tip moth on trees fertilized with nitrogen. Application of phosphorus, however, resulted in a significant tip-moth reduction. MEEKER (1988) found that decreasing infestation rates were related to phosphorus levels in soil and foliage, but increasing infestations were associated with increases in foliar nitrogen. Intensive vegetation management, which tended to reduce diversity in young pine stands, also resulted in increased NPTM infestation rate (HERTEL and BENJAMIN, 1976; WHITE et al., 1984).

Both fertilizer and herbicide applications are known to affect oleoresin production as well as water status of host pine trees. Oleoresin production is considered the most important physiological defence against NPTM larvae (YATES, 1966; HODGES et al., 1977; BERISFORD, 1988) and is greatly affected by tree water condition (KRAMER and KOZLOWSKI, 1979; LORIO and SOMMERS, 1986; ROSS and BERISFORD, 1990).

In the south-eastern United States, in young pine plantations, particularly in Christmas tree farms, fertilizer and herbicide applications are accepted tools for increasing forest land productivity. A better understanding of the effects of fertilization and herbicide release on NPTM infestation would contribute to a comprehensive integration of NPTM management in overall pine plantation management. The objectives of this study were to evaluate the effects of fertilizer and herbicide application on NPTM infestations, host oleoresin production, host tree moisture stress, and NPTM pupal weight.

2 Materials and methods

2. 1 Study site

Experiments were conducted at two sites in 1988 and 1989. The two sites were located in Lilbert, 40 km north-west of Nacogdoches, TX. Site 1 (1988 experiment) is a Mollville–Besner complex soil having a site index of 90 for loblolly pine. The loblolly pine plantation was planted in 1986 and had heavy vegetation competition. Mollville soils made up 45% of the complex, Besner soils 35%, and other soils 20%. Site 2 (1989 experiment) was located 3 km south of site 1, was Sacul fine sandy loam (Clayey, mixed, thermic Aquic Halpudult). It

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had a site index of 80 for loblolly pine (USDA Soil Conservation Service, 1980). Loblolly pine seedlings were planted in 1988, and the tip moth infestation was almost zero at the time of plot establishment (February 1989). Foliage and nutrient analysis were conducted before the treatment which showed nutrient deficiency at both sites but no significant differences among the experimental plots.

2.2 Treatment

Six treatments were randomly assigned to 16 plots of 0.25 ha with three replicates for each treatment in site 1. Each plot consisted of 10 rows of 20 trees. Buffer zones of 15 m were left between plots. The six treatments were: (1) phosphorus fertilization using 0–46–0, concentrated superphosphate at 224 kg/ha elemental phosphorus (P); (2) herbicide application (H) consisted of a combined Oust (sulformeturon methyl) at a rate of 280 gm/ha and Velpar-L (hexazinone) at 1.2 l/ha; (3) calcium fertilization using gypsum, $CaSO_3$ (Ca) at 224 kg/ha elemental calcium; (4) combined fertilization of nitrogen (ammonium nitrate, 34–0–0) and phosphorus (NP) at 224 kg/ha elemental level; (5) combination of nitrogen at 224 kg/ha element, phosphorus at 224 kg/ha element and herbicide of both Oust (280 gm/ha) and Velpar-L(1.2 l/ha) (NPH); and (6) control (C). Fertilizer was applied by hand on a tree by tree basis in April 1988; and herbicide application was made in May 1988 using a tractor with boom sprayer.

A randomized block experimental design was employed at site 2. Each block consisted of 10 rows of 15 trees in site 2. The treatments were randomly assigned to each block with each treatment appearing once in each block. Fertilizer was applied in April 1989. However, we only used four treatments [phosphorus fertilization (P) at 224 kg/ha element, nitrogen fertilization (N) at 224 kg/ha element, combination of nitrogen and phosphorus (NP) and control (C)] in this study in order to collect data on resin and pupal weight.

2.3 Data collection

2.3.1 Infestation

The 30 sample trees in site 1 and 15 in site 2 per plot were used to determine NPTM infestation level at the end of the 1988 and 1989 growing seasons. Whole tree infestation was calculated as the ratio of apparently infested tips to total tips. The infestation counts were conducted twice, before and after the 1988 treatment, and only once after the 1989 treatment because infestation was nil before the treatment. Tips counted as infested were those exhibiting browning, curling, dieback and oleoresin globules.

2.3.2 Tree xylem moisture potential

The internal water status within host trees was monitored periodically during the growing season in 1988 using the pressure chamber technique (Scholander et al., 1965). This technique was used to measure xylem moisture potential in an effort to relate it to the tip moth infestation. Moisture readings were taken every 4–5 weeks. One to four samples were clipped from the upper one-third of sample tree crowns where NPTM attacks were concentrated and exposure to the sunlight was the greatest. The moisture content of the sample was measured in the field immediately after cutting. All measurements were taken during the approximate peak stress interval of 1200 to 1400 h on sunny days. Measurements were recorded in pounds per square inch (psi) required to force water to the cutting surface of the severed twig and converted to megapascals (MPa) by the equation: MPa = (psi × 0.06895)/10.

2.3.3 Oleoresin production

Growing shoots of young seedlings were severed 2.5 cm below the tip and oleoresin was allowed to gather for 30 min. The exuded droplets of oleoresin were collected on a previously weighed microscope cover slip, then reweighed to the nearest one-thousandth gram. All sample shoots chosen for sampling were similar in diameter to minimize sample difference.

2.3.4 Pupal weight

Infested tips were randomly collected from the trees treated with N, P, NP and control in 1989. The tips were dissected and pupae were then weighed to the nearest one-thousandth gram.

2.3.5 Tip nutrient contents

To further understand tree nutrient status in relation with NPTM infestation in natural condition, tips from eight different young loblolly pine plantations in East Texas were collected randomly and their nutrients were analysed in three groups: (1) infested tips collected from tree infested by NPTM; (2) uninfested tip collected from tree infested by NPTM; (3) uninfested tips collected from tree uninfested by NPTM.

2.3.6 Tree growth and data analysis

Tree growth was measured as changes in height, basal diameter or volume before and after treatment. Data were analysed using the SPSS-X statistical package (SPSS Inc. 1983). Analysis of variance (ANOVA) was used to test for differences within infestation rates, xylem moisture potential and tree growth parameters. Duncan's test was used to separate the means ($P > 0.05$).

3 Results

There was no significant difference in infestation level before the treatment in 1988 (table 1). However, one-way ANOVA of NPTM infestation grouped by treatment showed that fertilization with either phosphorus or a combination of phosphorus and nitrogen resulted in increased NPTM attack with respect to the control. Addition of herbicide to the combination of phosphorus and nitrogen decreased infestation to a level similar to that observed in the control but not the application of herbicide alone. Fertilization with calcium induced the larger decrease, although it did not significantly differ from the control. There was no difference in nitrogen, phosphorus and potassium content among the three categories of tips which were randomly collected from eight different sites in East Texas. By contrast, there were significant differences in calcium content, uninfested tips from uninfested trees showed a higher calcium content (fig). Xylem moisture potential was lower in herbicide treatment than in control and fertilizer treatment (table 2).

Combined fertilization by nitrogen and phosphorus significantly decreased tree height, diameter and, consequently, volume growth (table 1). Other treatments did not induce significant growth decrease compared with the control. The NPH treatment achieved the best growth response, followed by the H treatment. It was apparent that herbicide stimulated tree growth by reducing competing vegetation.

Table 1. *Mean height, basal diameter, volume growth of loblolly pines (3-year-old) and NPTM infestation by treatment in 1988*

Treatment	Growth (After treatment measurement – before treatment measurement) Height (cm)	Diameter (cm)	Volume (cm^3)	Infestation (%) Before treatment	After treatment
C	108.47a	0.81b	280.78b	15.58a	11.18ab
P	106.85a	0.85b	257.73b	14.42a	15.38c
H	108.84a	0.93c	314.85bc	14.02a	13.50bc
Ca	109.34a	0.83b	286.34bc	13.08a	8.99a
NPH	114.36a	0.98c	322.80c	11.64a	10.44ab
NP	90.33b	0.71a	215.19a	13.01a	16.48c

Values within columns followed by the same letter are not significantly different (P = 0.05) using Duncan's multiple range test.
C, treatment of control; P, phosphorus; H, herbicide; Ca, calcium; NPH, combination of nitrogen, phosphorus and herbicide; NP, combination of nitrogen and phosphorus.

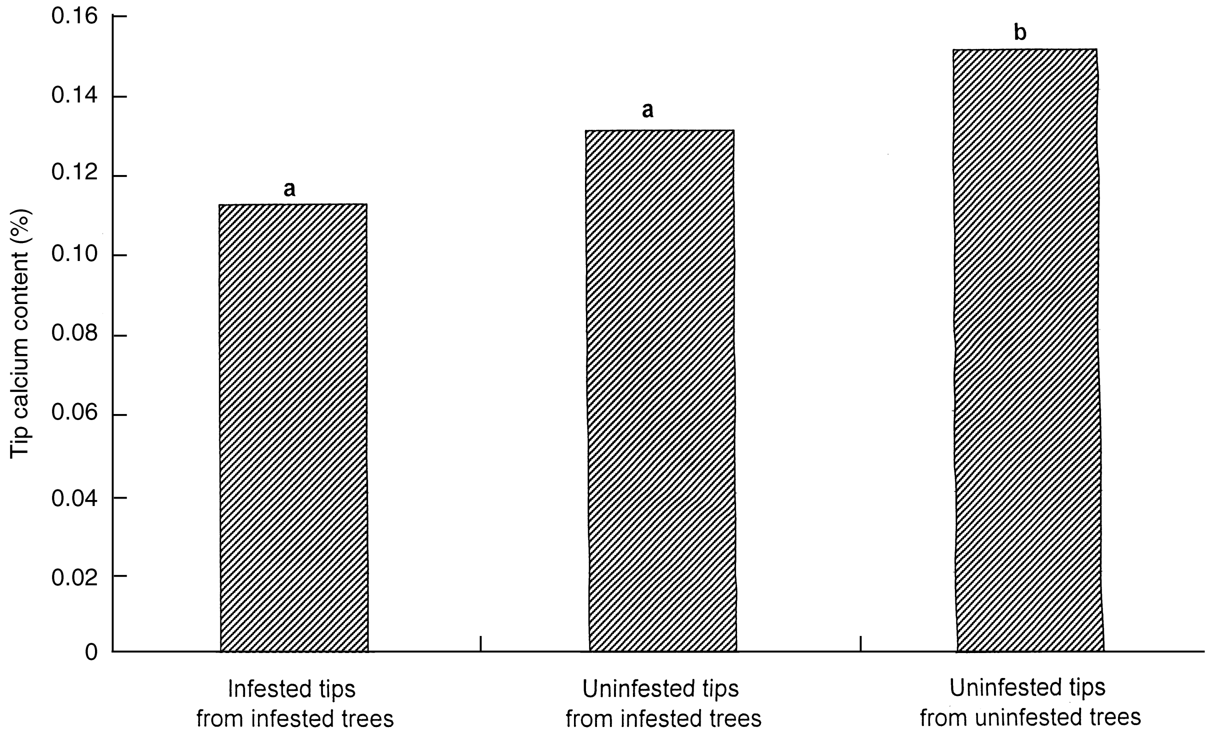

Figure. *Loblolly pine (3–5 years old) tip calcium content categorized by NPTM infestation in East Texas, 1988. Bars marked by the same letter are not significantly different (P = 0.05) using Duncan's multiple range test*

Fertilization with nitrogen resulted in a significantly higher infestation rate than other treatments in 1989 (table 3). N was significantly higher than the P and NP treatments. Phosphorus (P) treatment resulted in the lowest infestation. Fertilization may also have an effect on oleoresin production (table 3), but differences between the control were not significant. Trees treated with nitrogen produced the highest oleoresin production, followed by the phosphorus treatment. Effect of fertilization on NPTM pupal weight is shown in table 3. The mean weight of pupae from trees treated with nitrogen was significantly higher than those from the control and trees treated with phosphorus. Such differences in pupal weight between treatments may reflect variation in infestation since pupal weight is directly associated with fecundity.

4. Discussion

NPTM infestation increased at both site 1 and site 2, apparently because the nitrogen fertilization treatment made host tissue more succulent and nutritious to NPTM larvae. However, this treatment also increased the host tree moisture stress by promoting competing vegetation, thereby making the host more susceptible to NPTM attack. Our assumption is that nitrogen fertilization increased tip moth infestation; it increased the

Table 2. *Mean xylem moisture potential (psi) of loblolly pine by treatment in 1988*

Treatment	April	May	July	August	October
C	1.10a	1.46ab	1.58ab	1.75a	1.86a
P	1.25a	1.48ab	1.60ab	1.78a	1.98a
H	1.02a	1.30a	1.43a	1.74a	1.78a
Ca	1.10a	1.50ab	1.57ab	1.76a	1.85a
NPH	1.12a	1.37ab	1.53ab	1.76a	1.80a
NP	1.33a	1.59b	1.65b	1.84a	2.01a

Values within columns followed by the same letter are not significantly different (P = 0.05) using Duncan's multiple range test. C, treatment of control; P, phosphorus; H, herbicide; Ca, calcium; NPH, combination of nitrogen, phosphorus and herbicide; NP, combination of nitrogen and phosphorus.

Table 3. *Mean weights of pupae weight (mg) loblolly pines (2-year-old) resin production (30 min) and NPTM infestation by treatment in 1989*

	N	P	NP	C
Pupae (n = 138)	7.6a	6.7b	7.3a	6.8b
Resin (n = 73)	9.0a	8.1a	*	7.1a
Infestation (%)	31a	13b	18b	18b

Values within rows followed by the same letter are not significantly different (P = 0.05) using Duncan's multiple range test.
* No measurement in this treatment.
N, treatment of nitrogen; P, phosphorus; NP, combination of nitrogen and phosphorus; C, control.

pupal weight of tip moth feeding on those trees, and pupal weight is directly related to fecundity (BAKKE, 1969; ROSS et al., 1990). The behaviour of nitrogen treatment which makes the host succulent is related to drought stress (WHITE, 1974). That is, as stress increases, soluble nitrogen levels also will increase. Stressed hosts may then become more susceptible to NPTM attack. The combined treatment of nitrogen, phosphorus and herbicide resulted in relative low infestation compared with that observed in fertilizer treatment alone. Apparently, herbicide application reduced or suppressed competing vegetation and improved tree moisture status whereas fertilization stimulated tree growth, and hence increased tree vigour and enhanced tree resistance to NPTM. This result contrasted with those of similar studies in which tip moth damage increased following vegetation control, by reasoning that herbicides may have an adverse effect on NPTM natural enemies and increased access for NPTM host-finding (WARREN, 1963; BERISFORD, 1988; RUSSELL, 1989; ROSS and BERISFORD, 1990). The combined treatment of herbicide and fertilizer achieved the best growth response, followed by herbicide treatment. Fertilization alone not only failed to obtain the desirable growth response due to increased vegetation, but also increased tree moisture stress as a result. Another added advantage is that this fast growth tends to shorten the period of heavy NPTM attack. However, heavy NPTM attack also slowed tree growth. So, this complex clearly suggested there was a significant interaction among fertilization, vegetation control, NPTM infestation and tree growth. But, it is evident that reduced competing vegetation is a leading factor in this complex which can result in substantial gains in growth. Additional growth gains can also be realized from reduced NPTM infestation, and the tree appearance or tree form is significantly improved. Precaution should be exercised even though we have four growths per year in Texas, the long-term impacts are not known from this and other similar studies.

Phosphorus treatment in the 1989 experiment resulted in a relative low infestation, however, that was not significantly different from the control but the trend was obvious. Large amounts of oleoresin can drown (pitch out) tip moth larvae (YATES, 1966). Differences in terpene composition were also assumed to be responsible for the sensitivity of European black pine (*Pinus nigra*) to the European pine shoot moth (*R. buoliana*) with provenance (CHARLES et al., 1982). In this respect, it is most likely that applications of certain fertilizers would affect host tree oleoresin composition which will lead to tip moth resistance. Observations made during our oleoresin collection indicated that the degree of crystallization of oleoresin during the periods of 30 min and 2 h were different between the treatments. Oleoresin droplets from trees treated with high phosphorus levels developed a hard amorphous coating that was clear and not sticky to touch whereas droplets from trees in control plots remained quite soft on the surface after 2 h.

Calcium and site index account for the large variation in NPTM infestation (SUN et al., 1998). This result is very similar to a study by HOOD et al. (1988), but the mechanism of this effect remains poorly understood. Very low infestation in the calcium treatments was unexpected, but no conclusion can be drawn at this point. However, we speculate that calcium may harden shoot tissue since it is a major component of plant cell wall, thereby making the tissue less succulent for NPTM feeding. This suggests that calcium may thus add a certain degree of resistance against NPTM attack in loblolly pine although the relationships between calcium and NPTM infestation are not clear.

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Authors' address: Dr JIANGHUA SUN (corresponding author), Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China. E-mail sjh@public.hz.hl.cn