INTERACTION OF FOREST MANAGEMENT PRACTICES AND TIP MOTH DAMAGE

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Abstract—Intensive forest management practices have been shown to increase tree growth and shorten rotation time. However, they may also increase the need for insect pest management because of higher infestation levels and lower action thresholds. The Nantucket pine tip moth (*Rhyacionia frustrana* [Comstock]) is one insect that is expected to become more important with more intensive forest management practices. Two studies were developed to investigate these relationships. Treatments included various combinations of herbicide applications, irrigation, fertilization, and insecticide applications. These studies demonstrated that tip moth management improves tree growth. Tip moth damage increased due to weed control, but not due to N fertilization. Nitrogen fertilization did increase the number of tip moth pupae per shoot, however. In conclusion tip moth populations can increase due to intensive management practices, and insect control should be considered a part of efforts to maximize tree growth.

INTRODUCTION

The demand for forest products in the United States is growing while the land base for producing these commodities is shrinking as a result of conversions to other uses, increased land fragmentation, and concerns about endangered species and old growth forests. In order to meet timber and fiber needs, commercial forests must be managed more efficiently. Intensive management practices, such as herbaceous weed control, irrigation, and fertilization can increase tree growth and shorten rotation time (Pritchett and Smith 1972, Haywood 1986, Zutter and others 1986, Creighton and others 1987). Unfortunately, they may also increase the frequency and severity of pest infestations (Hedden and Nebeker 1984, Ross and others 1990). There is a critical need for studies on the effects of intensive forest management practices on pest insect populations.

Loblolly pine (*Pinus taeda* L.) is the most commercially important tree species in the southeastern United States. Several insects are associated with young stands of loblolly pine and are likely to become more important as management intensity increases. The Nantucket pine tip moth (*Rhyacionia frustrana* [Comstock]), is one such species (Sun and others 1998). Feeding by tip moth larvae can decrease tree growth in the early years following stand establishment (Warren 1964, Beal 1967, Lashomb and others 1978, Berisford and others 1989). Tip moth infestation levels often vary with intensity of silvicultural manipulations, such as mechanical site preparation, herbaceous weed control, and fertilization (Hertel and Benjamin 1977, White and others 1984, Ross and Berisford 1990, Ross and others 1990). Miller and Stephen (1983) concluded that differences in vegetation levels were not a good indicator of tip moth damage. However, Ross and others (1990) found that herbicide-treated plots had signicantly more tip moth damage than control plots during the first two growing seasons of a study conducted on the upper Coastal Plain of Georgia. Pritchett and Smith (1972) showed significant reductions in tip moth damage levels related to phosphorus (P) and potassium (K) fertilization, but no differences were observed after nitrogen (N) fertilization.

In January 1995, International Paper Corporation established a study of loblolly pine at their Southlands Experimental Research Forest near Bainbridge, GA to determine the maximum growth potential of loblolly pine using several hierarchies of cultural treatments. We examined the pest problems associated with these intensively managed loblolly pine within the first five years following stand establishment. Our objectives were to monitor insect pest establishment and to quantify insect associated growth losses among the different silvicultural treatments. A second study was established in 1999, near Powelton, GA to further examine the effects of fertilization and herbicide application on tip moth development and infestation levels.

MATERIALS AND METHODS

Bainbridge Study

This study was conducted in Decatur County, GA, about 20 km south of Bainbridge. The soil type was classified as a Wagram-troup complex and the site index was estimated to be 59 (base age 25; loblolly pine) (Personal communication. Tom Cooksey, Southlands Experiment Forest, International Paper Corp., Bainbridge, GA, 31717). The main study area was established on an old agricultural field that had been used to grow soybeans and watermelon. The surrounding plant community included a mixture of agricultural crop lands, hardwood forests, and longleaf (*Pinus palustris* Mill.) and loblolly pine forests of varying age classes.

A randomized complete block design with three blocks of four treatments was established. Each treatment plot was 0.2 ha, and contained 216 1-0 seedlings (grown for one year in the nursery before being planted in the field) (12 rows of 18 seedlings) hand planted in January 1995. One row on the end of each plot was designated as a border row and

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excluded from subsequent evaluations of insect infestation. Four improved loblolly pine seed sources from a nursery in North Carolina were blocked randomly within each plot. The site was subsoiled on 4 m centers and harrowed two months prior to planting. Sulfometuron (Oust®) (0.28 kg [AI]/ha) herbicide was applied once prior to planting and glyphosphate (Accord® 1.8 kg [AI]/ha) was applied twice prior to planting and then monthly during the growing season throughout the study to minimize herbaceous weeds.

The treatments were herbaceous weed control (H), H + irrigation (I), H + I + fertilization (F), and H + I + F + pest control (P). In the original study design, the control treatment was the H treatment. However, because weed control has been shown to influence tip moth damage levels (Ross and others 1990), we included three additional control plots in a nearby stand that represented more typical forest management. The control stand (C), approximately 250 ha in size, was located <1 km north of the main study site and contained 1-0 seedlings machine planted concurrently with the main study site. Except for a site preparation application of herbicides (Sulfometuron) and a prescribed burn prior to planting, competing vegetation was not managed in this stand. A number of factors besides weed control could contribute to differences between the control plots and the more intensively managed main study plots. However, we believe that these comparisons provide useful information regarding the potential differences between intensive cultural practices and traditional forest management.

A dripline irrigation and fertigation (water and nutrients) system (Netafim Irrigation, Altamonte Springs, FL) was used to add water and nutrients. Water was pumped directly from a nearby lake onto the treatments receiving irrigation on a nightly interval at a rate of 18 cm per year. Nitrogen was applied to the treatments receiving fertilizer at rates of 45 kg/ha in 1995, 79 kg/ha in 1996, 133 kg/ha in 1997 and 111 kg/ha in 1998 using an 8-2-8 liquid fertilizer formulation. Fertilizer applications were distributed evenly from April through November. Permethrin (Pounce® 3.2 EC, FMC Corporation, Philadelphia, PA) (1.1 kg [AI]/2.5 ha) and acephate (Orthene® 75 Turf, Tree and Ornamental, Valent USA Corp.) (2.2 kg [AI]/78 liters) were applied separately with backpack sprayers (Solo®, Newport News, VA) to the H+I+F+P treatment throughout each growing season at biweekly intervals in 1995–1997. Insecticide applications were discontinued for the first seven months of 1998, but were resumed in September. The insecticide treatments had been discontinued because of the large size of the trees and the lack of tip moth in the previous two years.

Nantucket pine tip moth damage was evaluated three times annually following the first, second, and combined third and fourth generations. The third and fourth generations were combined into one evaluation date because of considerable damage overlap between these two generations (Berisford and others 1992). Evaluation dates were timed to coincide with either the tip moth pupal stage or just after adult emergence (Ross and Berisford 1990). Forty trees per treatment per block were randomly selected on each evaluation date. All shoots were examined for tip moth damage during each evaluation in 1995–1997. However, due to the size of the trees in 1998, only the terminal and top 2 branch whorls were examined. There is a significant correlation between terminal and top whorl damage and whole tree damage (Fettig and Berisford 1999). Damage was recorded as the percentage of damaged shoots; a shoot was defined as an apical meristem containing at least 5 cm of foliage.

Basal diameter and total height were measured following each growing season. For comparative purposes, a tree stem volume index was calculated by multiplying the square of the basal diameter times height (D^2H). This volume index has been shown to correlate well with above-ground biomass (Hatchell and others 1985).

The control treatment means for insect damage were qualitatively compared to the combined means of the main study area because the control area was separate from the main study design. The growth data for the control site are included to illustrate the potential growth gains from intensive forestry. However, because factors other than weed control (i.e. site preparation and genetic source) could also have influenced insect damage levels and growth differences, statistical comparisons are not made between the main study site and the control site representing typical forest management. The data are included only to provide comparisons between typical forest management and intensive cultural practices for potential growth gains and implications for insect population dynamics.

Powelton Study

This study was conducted in Hancock County, GA near Powelton in 1999. A randomized complete block design was established in a two-year-old loblolly pine plantation. Each treatment plot was about 0.05 ha and had been machine planted with about 100 1-0 seedlings. The treatments were control, N fertilization (N-Fert), herbicide (Herb), and herbicide and N fertilizer (Herb-N).

The herbicide and fertilizer treatments were applied on 5 May and 21 July. The N fertilizer was applied at a rate of 107 kg/ha of elemental N in the form of 46 percent elemental urea. Glyphosphate (Accord® 1.8 kg [AI]/ha) was applied with backpack sprayers (Solo®, Newport News, VA). Treatment trees were covered with plastic bags for <15 min during herbicide application because glyphosphate is activite on pine trees.

Twenty-five trees per treatment per block were randomly selected on each evaluation date. Tip moth damage was evaluated on a whole tree basis three times annually following each of the three generations in a manner consistent with the Bainbridge study. Fifty tip moth infested shoots per treatment per block were collected near the end of the third generation and returned to the laboratory for examination. For each shoot, length of tip moth damage, number of insects, and life stages present were recorded.

Statistical Analysis

Tip moth infestation percentages were arcsine square root transformed and subjected to an analysis of variance (ANOVA) by each evaluation date. The insect damage data

are reported as the non-transformed means. Tree growth data were compared by ANOVA for each evaluation date. Insect damage and growth treatment data were analyzed as a randomized complete block design and means were separated using Proc GLM and Tukey's Studentized Range Test (SAS Institute 1988).

RESULTS

Bainbridge Study

Tip moth damage levels exceeded 10 percent only twice during this study, in 1995 and 1998 (fig. 1). Tip moth damage reached moderate levels in the third and fourth generation of 1995 and then dropped below 3 percent in 1996 and 1997 in the main study area. At the end of 1998, tip moth damage was ca. 80 percent in the main study area. Damage in the control treatment never exceeded 30 percent, even when damage was relatively high in the main study area.

No significant differences were detected in tip moth damage among the H, H+I, and H+I+F treatments in any year ($P > 0.05$; Tukey test) and these treatments are combined for analysis (fig. 1). Percent damage was significantly higher for these treatments than the H+I+F+P treatment during the highest infestation periods (generations 3 & 4 in October 1995 ($F = 25.46$; d.f. = 3,6; $P = 0.0008$) and October 1998 ($F = 13.55$; d.f. = 3,6; $P = 0.0044$)) (fig. 1). However, at lower damage levels, no significant differences were found. Tip moth damage levels were noticeably higher in the main study area than in the control area during the periods of highest infestation (fig. 1). There were no significant differences in tip moth damage levels among the four different seed sources used in the main study area ($P > 0.05$).

Significant differences were observed in height and volume among all treatments during 1995 and 1996 (figs. 2 and 3). The H+I+F+P treatment had significantly greater height and volume measurements than the other treatments at the end of 1995, 1996, and 1998. In 1997, there was no significant difference in height between the H+I+F treatment and the H+I+F+P treatment (fig. 2), but the H+I+F+P treatment had a significantly greater volume index (fig. 3). There was no significant difference in height between the H+I and H+I+F treatments in 1998, but the H+I+F treatment had a significantly higher volume index (fig. 3). The control treatment had the lowest values for height and volume measurements throughout the study (figs. 2 and 3).

Powelton Study

Tip moth damage ranged between 16 and 39 percent (fig. 4). There were no treatment differences in the second tip moth generation. However, significant differences were detected with ANOVA within treatment for percent tip moth infestation ($F = 5.03$; d.f. = 3,6; $P = 0.0446$), number of pupae per shoot ($F = 13.66$; d.f. = 3,6; $P = 0.0043$), and tree diameter ($F =$

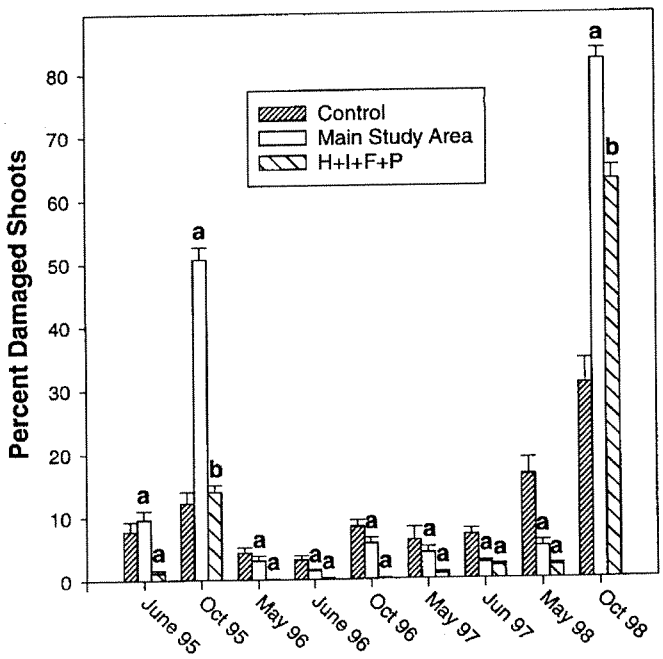

Figure 1—Mean percent (+/-SE) of loblolly pine shoots damaged by Nantucket pine tip moth during 1995–1998 in Bainbridge, GA. Three treatments means [herbicide (H), H + irrigation (I), and H + I + fertilizer (F)] are classified as the Main Study Area for simplicity and the lack statistical differences ($P > 0.05$;Tukey test). Bars with the same letter for each sample date are not significantly different (n = 480; $P > 0.05$; Tukey test). Control means (n = 120) are provided for comparative purposes only and are not included in the statistical analysis.

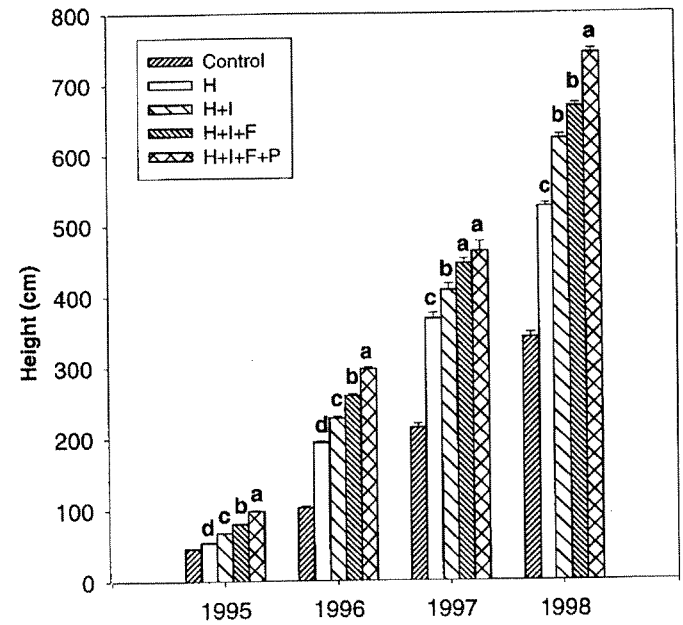

Figure 2—Mean tree height (+/-SE) for four growing seasons in a study conducted in Bainbridge, GA, following yearly cultural treatments: Herbicide (H), H + irrigation (I), H + I + fertilizer (F), and H + I + F + pest control (P). Bars with the same letter are not significantly different (n = 480; $P > 0.05$; Tukey test). Control means (n = 120) are provided for comparative purposes only and are not included in the statistical analysis.

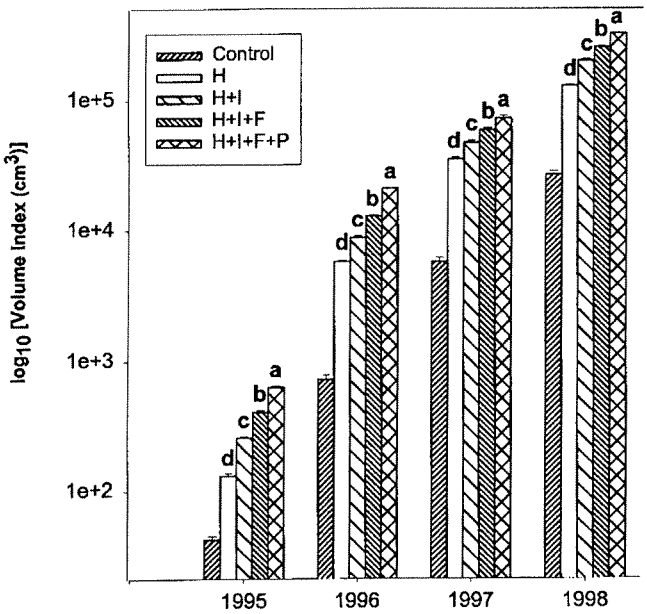

Figure 3—Mean tree volume index (+/-SE) (basal diameter-squared times height) for four growing seasons in a study in Bainbridge, GA following yearly cultural treatments: Herbicide (H), H + irrigation (I), H + I + fertilizer (F), and H + I + F + pest control (P). Bars with the same letter are not significantly different (n = 480; $P > 0.05$; Tukey test). Control means (n = 120) are provided for comparative purposes only and are not included in the statistical analysis.

10.42; d.f. = 3,6; $P = 0.0086$) at the end of the third generation. Tip moth damage was significantly higher in the Herb-N and Herb treatments than in the control treatment (fig. 4). Mean number of tip moth per shoot ranged between 0.33 and 0.78 (fig. 5). There were significantly more pupae in the Herb-N treatment than in any of the other treatments, but none of the other treatments varied statistically (fig. 5). Mean tree diameter was significantly greater in the Herb and Herb-N treatments than in the N-fert and control treatments, which did not differ significantly (fig. 6). However, there was no treatment difference in tree height ($F = 1.97$; d.f. = 3,6; $P = 0.2205$).

DISCUSSION

Tip moth damage in the Bainbridge study was at the highest level after the trees had exceeded what is normally considered susceptible size (Berisford 1988). Because of the absence of significant tip moth infestation after the 1995 growing season, it was thought that the trees in the more intensive treatments may have simply outgrown their susceptibility to attack in the first growing season. However, the high tip moth damage in 1998 dispelled this hypothesis. It was thought that perhaps the pitch pine tip moth (*R. rigidana* [Fernald]) was causing the infestation in 1998 because *R. rigidana* are more common in taller trees than *R. frustrana* (Berisford 1988). However, the moths were identified as *R. frustrana* based on Yates' (1967) key.

In the Bainbridge study, tip moth infestation levels fluctuated more in the main study area without competing vegetation than in the control area with competing vegetation. Similar fluctuations were found by Miller and Stephen (1983), where

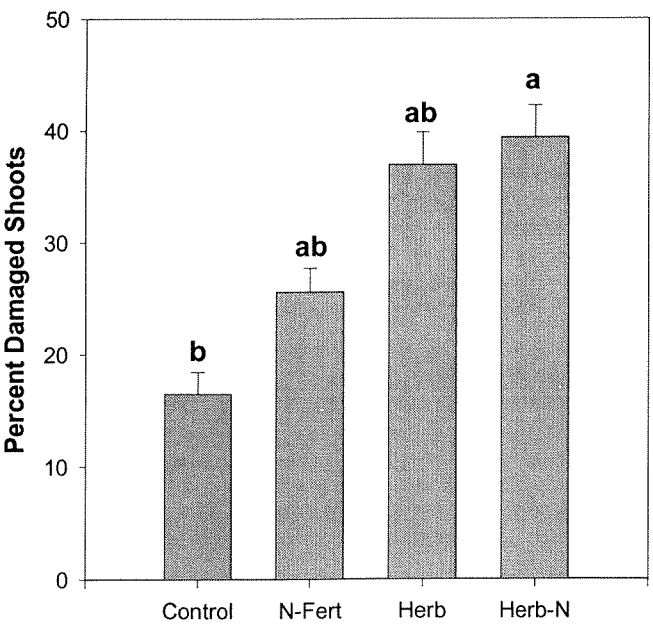

Figure 4—Mean percent (+/-SE) of loblolly pine shoots damaged by Nantucket pine tip moth during the third tip moth generation of 1999 in a study in Powelton, GA following cultural treatments: control, N fertilization (N-fert), herbicide (Herb), and herbicide application and N fertilization (Herb-N). Bars with the same letter for each sample date are not significantly different (n = 240; $P > 0.05$; Tukey test).

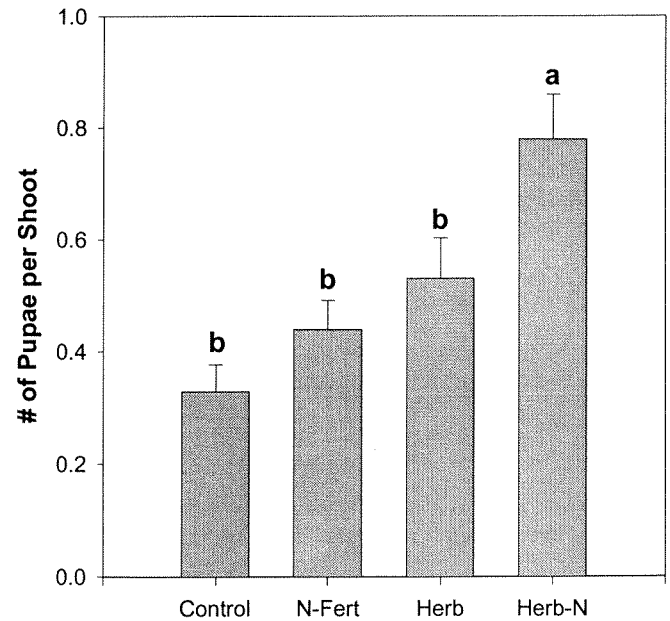

Figure 5—Mean number of tip moth pupae per shoot (+/-SE) for the third tip moth generation in a study conducted in Powelton, GA, following cultural treatments: control, N fertilization (N-fert), herbicide (Herb), and herbicide application and N fertilization (Herb-N). Bars with the same letter are not significantly different (n = 300; $P > 0.05$; Tukey test).

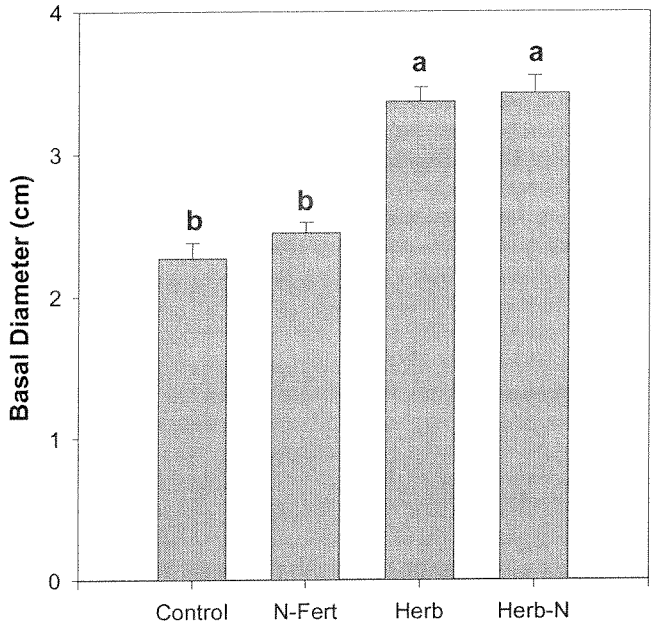

Figure 6—Mean tree diameter (+/-SE) for the third tip moth generation in a study conducted in Powelton, GA, following cultural treatments: control, N fertilization (N-fert), herbicide (Herb), and herbicide application and N fertilization (Herb-N). Bars with the same letter are not significantly different (n = 240; $P > 0.05$; Tukey test).

tip moth damage levels fluctuated more in areas with low competing vegetation than in areas with high vegetation levels. Tip moth population levels in areas with competing vegetation appear to be more stable than populations in areas without competing vegetation. One possible reason for this could be that the tip moth natural enemy complex exerts a more consistent influence in areas with herbaceous weeds, perhaps because of a more favorable microclimate and the presence of food sources such as pollen and nectar (Pimentel 1961, Strong 1984). In a previous study, total parasitism was higher in areas with competing vegetation than in adjacent areas with significantly less vegetation (McCravy and Berisford *In press*). However, parasitism data were not collected in this study.

Irrigation and fertilization significantly increased tree growth, but did not affect tip moth infestation levels. In a greenhouse study, Ross and Berisford (1990) concluded that management practices that increase water and nutrient availability to loblolly pine increase the amount of tip moth infestation. Results of the fertilization treatments are consistent with other studies concerning the effects of fertilization on tip moth infestation levels (Pritchett and Smith 1972, Berisford and others 1989). However, none of these studies, including this one, accounted for the number of tip moth larvae or pupae per individual shoot. Ross and Berisford (1990) found that pupal densities were significantly higher in potted seedlings with high nutrient levels. More intensive studies are needed to investigate the effects of fertilization on the amount of tip moth attacks and subsequent infestation. If N fertilization increases tip moth infestation, it might not be economically feasible to apply fertilizer if growth gains were lost to insect infestation. On the other hand, it is possible that fertilization could be used to increase tree vigor and thereby reduce the impact of tip moth infestation.

The Powelton study was designed to further evaluate the effects of fertilization and weed control on tip moth damage levels and development. It has been shown that a reduction in competing vegetation can lead to an increase in tip moth damage levels (Miller and Stephen 1983, Ross and others 1990). However, the Bainbridge study did not adequately address this issue because a true control was not included in the original study design. In the Powelton study, herbicide applications reduced competing vegetation and subsequently increased tip moth damage. Herbicide applications coupled with N fertilization also increased the number of pupae per shoot. This indicates that intensive forest management practices such as herbaceous weed control can increase tip moth populations and subsequent damage.

In the Powelton study, we found that fertilization alone did not increase tip moth damage or the number of pupae present per shoot. However, there were also no differences in tree height or diameter due to N fertilization. The Powelton study has only lasted one year and tip moth damage estimates were only recorded in one generation after the plots were treated. It is possible that the trees and also the insects have not had time to respond the N fertilization. The Powelton study will continue for three more generations and foliar analysis will be performed. It is too early in the experiment to conclude that N fertilizer will not have an effect on tip moth damage levels or on insect development in contrast to Ross and Berisford (1990).

Insecticide applications increased tree growth 27 percent over the H+I+F treatment even though tip moth infestations in the Bainbridge study were low compared to many other studies (Lashomb and others 1978, Miller and Stephen 1983, Ross and others 1990). In 1998, the insecticide applications were discontinued because of low insect infestation in the previous two years. The applications were resumed once heavy damage began to reappear in September of 1998. Therefore, tip moth infestation in the pest control plots was significantly lower than the other treatments, but could have been even lower if insecticide applications had been made in a manner consistent with previous years. It has been argued that growth losses due to tip moth infestation are transitory (Williston and Barras 1977); however, this was not evident in our four year study. Future growth measurements are intended. Longer-term studies have shown that growth increases due to tip moth management are maintained (Cade and Hedden 1987, Unpublished data. Wayne Berisford, Department of Entomology, University of Georgia, Athens, GA, 30602).

In conclusion, intensive forest management practices such as herbaceous weed control and N fertilization can in some cases exacerbate tip moth problems and may disrupt tip moth population dynamics. However, tip moth control can reduce grow losses associated with feeding damage.

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