Effects of Intensive Forest Management Practices on Insect Infestation Levels and Loblolly Pine Growth

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ABSTRACT Intensive forest management practices have been shown to increase tree growth and shorten rotation time. However, they may also lead to an increased need for insect pest management because of higher infestation levels and lower action thresholds. To investigate the relationship between intensive management practices and insect infestation, maximum growth potential studies of loblolly pine, *Pinus taeda* L., were conducted over 4 yr using a hierarchy of cultural treatments. The treatments were herbaceous weed control (H), H + irrigation (I), H + I + fertilizer (F), and H + I + F + pest control (P). These treatments were monitored for differences in growth and insect infestation levels related to the increasing management intensities. The Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock), was consistently found infesting study trees. In the third field season, the H + I + F + P treatment had significantly more southern pine coneworm, *Dioryctria amatella* (Hulst), attacks than the H and H + I treatments. There were significant differences in volume index (D^2H) among all treatments after each of the four growing seasons. This study indicated that tree fertilization can increase coneworm infestation and demonstrated that tip moth management can improve tree growth initially. Future measurements will determine if the growth gains from tip moth management are transitory or sustainable.

KEY WORDS *Rhyacionia frustrana, Dioryctria amatella, Pinus taeda,* intensive forestry

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. To meet timber and fiber needs, commercial forests must be managed more efficiently. Intensive management practices, such as herbaceous weed control, irrigation, and fertilization, will be the cornerstones of this effort. These cultural practices can increase tree growth and shorten rotation time (Pritchett and Smith 1972, Haywood 1986, Zutter et al. 1986, Creighton et al. 1987), but may also increase the frequency and severity of pest infestations (Hedden and Nebeker 1984, Ross et al. 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 recently regenerated 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 et al. 1998). Feeding by tip moth larvae causes terminal bud and shoot death, which can decrease tree growth in the early years after stand establishment (Warren 1964, Beal 1967, Lashomb et al. 1978, Berisford et al. 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 et al. 1984). Miller and Stephen (1983) concluded that differences in vegetation levels after herbicide treatments did not lead to differences in tip moth damage. Ross et al. (1990) found that herbicide-treated plots had significantly 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 a study in the upper Coastal Plain of Georgia, tip moth damage levels were significantly lower in the insecticide-herbicide-fertilizer treatment than in the insecticide-herbicide treatment in one year but were not significantly different in the two other years of the experiment (Berisford et al. 1989).

Coneworms (*Dioryctria* spp.) (Lepidoptera: Pyralidae) are generally not of concern in production forests, but can cause significant damage in loblolly pine seed orchards (Ebel et al. 1975). Coneworms often complete their life cycle in fusiform rust galls caused by the fungus *Cronartium quercuum* f. sp. *fusiforme* (Coulson and Franklin 1970) and have recently been observed feeding in loblolly pine stems in intensively managed experimental plantations (R. S. Cameron, International Paper, Rincon, GA, personal communication). Carisey et al. (1994) showed that *Dioryctria sylvestrella* Ratzeburg tended to attack the fastest growing trees in a stand of maritime pine, *P. pinaster*

Ait. Sarajisthvili (1997) concluded that stands influenced by high nitrogen soil deposits tended to be more susceptible to *Dioryctria* attack than trees growing in less fertile soils. Therefore, it is possible that coneworms could increase in importance with increased 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 4 yr after stand establishment. Our objectives were to monitor insect pest establishment and to quantify insect associated growth losses among the different silvicultural treatments.

Materials and Methods

This study was conducted in Decatur County, GA, ≈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) (T. Cooksey, International Paper, Bainbridge, GA, personal communication). 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 0.2-ha treatment plot contained 216 1–0 seedlings (grown for 1 yr 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 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 main study site was subsoiled on 4-m centers and harrowed 2 mo before planting. Sulfometuron (DuPont, Wilmington, DE) (Oust) (0.28 kg [AI]/ha) herbicide was applied once before planting and glyphosphate (Accord (Roundup, Monsanto, St. Louis, MO) 1.8 kg [AI]/ha) was applied twice before 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 et al. 1990), we included three additional control plots in a nearby stand that represented more typical forest management. The control stand (C), ≈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 and a prescribed burn before 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/yr. 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 (N:P:K) liquid fertilizer formulation. Fertilizer applications were distributed evenly from April through November. Permethrin (Pounce 3.2 EC[emulsifiable concentrate], FMC, Philadelphia, PA) (1.1 kg [AI]/2.5 ha) and acephate (Orthene 75 Turf, Tree and Ornamental, Valent, Walnut Creek, CA) (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 8 mo of 1998, but were resumed in September. The insecticide treatments were discontinued because of the large size of the trees and the lack of tip moth in the previous 2 yr.

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

Coneworm damage was recorded for 40 sample trees per plot after damage was initially detected in September 1997. Each larval entrance hole was counted as one coneworm attack. Damage was reported as the number of attacks per stem and the percentage of trees attacked per treatment. Coneworms were identified as southern pine coneworm, *Dioryctria amatella* (Hulst), by rearing larvae excavated from the trees to adulthood.

Basal diameter and total height were measured immediately after the first three growing seasons in the main study area and in the control plots. Growth measurements for the fourth year were not taken until April of the fifth year because of time constraints. 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 (Tiarks and Haywood 1981, Hatchell et al. 1985).

Tip moth infestation densities were arcsine square-root transformed and subjected to an analysis of variance (ANOVA) by each evaluation date. The number of *Dioryctria* spp. stem attacks was transformed by taking the log of the square root. The insect damage data are reported as the nontransformed 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 the Tukey studentized range test (SAS Institute 1985).

The control treatment means for insect damage were qualitatively compared with 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 is 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 plot representing typical forest management. The data are only included to provide comparisons between typical forest management and intensive cultural practices for potential growth gains and implications for insect population dynamics.

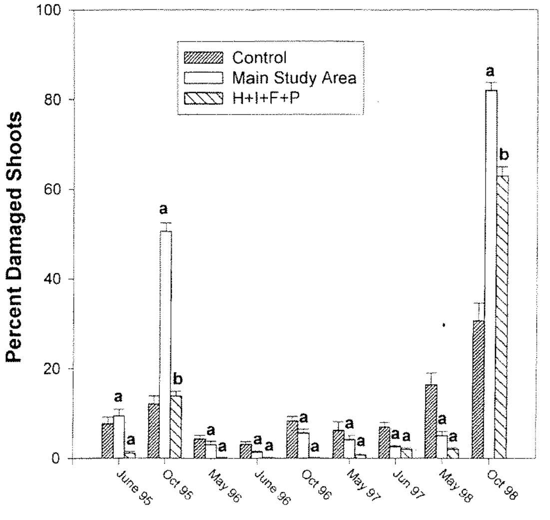

Fig. 1. Mean percent (±SE) of loblolly pine shoots damaged by Nantucket pine tip moth during 1995–1998. Three treatments means (herbicide [H], H + irrigation [I], and H + I + fertilizer [F]) are classified as the main study area for simplicity and the lack statistical differences ($P > 0.05$; Tukey test). The H + I + F + P treatment was statistically different from the other treatments. 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.

among the four different seed sources used in the main study area ($P > 0.05$).

Southern pine coneworm, *Dioryctria amatella* (Hulst), larvae were first observed feeding in the main stems and terminals in 1997. The H + I + F + P

Results

Tip moth damage levels exceeded 10% 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% in 1996 and 1997 in the main study area. At the end of 1998, tip moth damage was ≈80% in the main study area. Damage in the control treatment never exceeded 30%, 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 presentation (Fig. 1). Percent damage was significantly higher for these treatments than the H + I + F + P treatments during the highest infestation periods (generations three and four in 1995 ($F = 25.46$; df = 3, 6; $P = 0.0008$) and 1998 ($F = 13.55$; df = 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

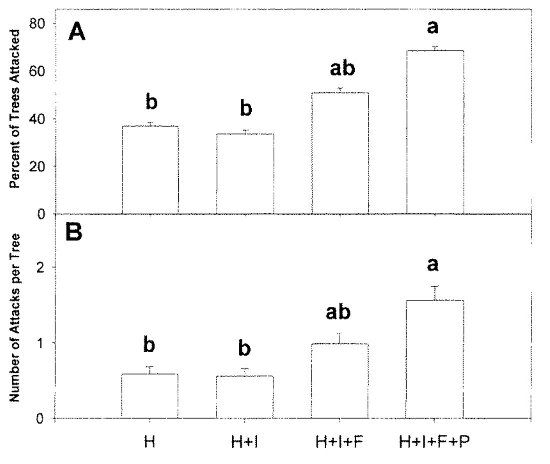

Fig. 2. Mean percent (±SE) of trees attacked (A) and mean number (±SE) of attacks per tree (B) by Southern pine coneworm on loblolly pine in the third growing season after various cultural treatments: herbicide (H), H + irrigation (I), H + I + fertilizer (F), and H + I + F + pest control (P). Bars with the same letter are not significantly different ($n = 480$, $P > 0.05$, Tukey test).

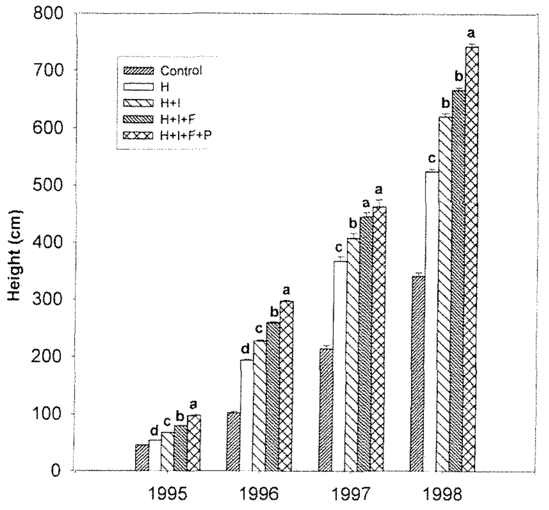

Fig. 3. Mean tree height (±SE) for four growing seasons after yearly cultural treatments: herbicide (H), H + irrigation (I), H + I + fertilizer (F), and H + I + F + pest control (P). Bars with the same letter are not significantly different (n = 480, $P > 0.05$, Tukey test). Control means (n = 120) are provided for comparative purposes only and are not included in the statistical analysis.

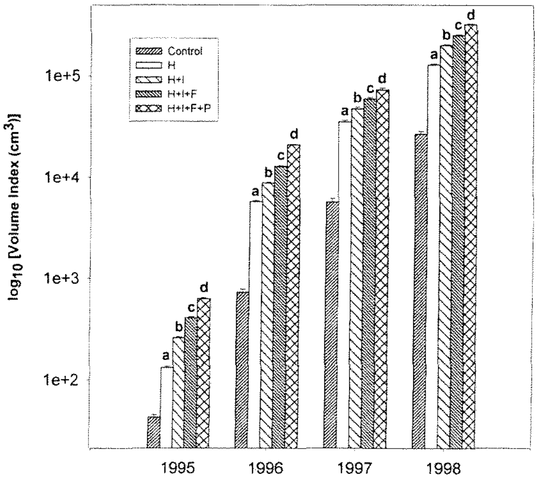

Fig. 4. Mean tree volume index (±SE) (basal diameter-squared times height) for four growing seasons after yearly cultural treatments: herbicide (H), H + irrigation (I), H + I + fertilizer (F), and H + I + F + pest control (P). Bars with the same letter are not significantly different (n = 480, $P >$ 0.05, Tukey test). Control means (n = 120) are provided for comparative purposes only and are not included in the statistical analysis.

treatment had significantly more trees attacked (F = 9.15; df = 3, 6; P = 0.0117) (Fig. 2A) and stem attacks per tree (F = 14.02; df = 3, 6; P = 0.0041) (Fig. 2B) than the H, and H + I treatments. Coneworm damage was not detected in the control plots. Aphids (*Cinara* spp.), Southern red mites, *Oligonychus ilicis* (McGregor); pine mealybugs, *Oracella acuta* (Lobdell); pine tortoise scale, *Toumeyella parvicornis* (Cockerell); striped pine scale, *T. pini* (King); pine webworm, *Tetralopha robestella* (Zeller), and redheaded pine sawfly, *Neodiprion lecontei* (Fitch), also were present at low densities.

Significant differences were observed in height and volume among all treatments during 1995 and 1996 (Figs. 3 and 4). The H + I + F + P treatment had significantly larger 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. 3), but the H + I + F + P treatment had a significantly greater volume index (Fig. 4). 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. 4). The control treatment had the lowest values for height and volume measurements throughout the study (Figs. 3 and 4).

Discussion

Tip moth damage in this study was at the highest level after the trees had grown past what is considered susceptible size (Berisford 1988). Because of the decrease in 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 considered that a congeneric, *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.

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). Tip moth population levels in areas with competing vegetation might 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). The vegetation in the control area consisted of the following plants: *Poaceae* spp., *Rubus* spp., *Smilax* spp., *Liquidambar styraciflua* L., *Rhus* spp., and *Quercus* spp. In a previous study, total parasitism was higher in areas with competing vegetation than in adjacent areas with significantly less vegetation (C.W.B., unpublished data). However, parasitism data were not taken in this study.

Irrigation and fertilization increased tree growth significantly, 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 will 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 et al. 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. However, it is possible that fertilization could be used to increase tree vigor and thereby reduce the impact of tip moth infestation.

In contrast to the effects on tip moth infestation, the faster growing trees had significantly more coneworm attacks. This was unexpected because coneworms are typically not of concern in production forests. However, coneworm feeding often resulted in considerable damage, in some cases killing the entire branch adjacent to their feeding site. When larvae were found in the terminal, up to 30 cm of the terminal was killed. Other studies have shown that coneworms more frequently damage vigorous trees (Whitham and Mopper 1985, Carisey et al. 1994, Sarajisthvili 1997). Coneworms have the potential to become important plantation pests because they cause considerable feeding damage and have several generations per year (Ebel et al. 1975).

Insecticide applications increased tree growth 27% over the H + I + F treatment even though tip moth infestations on this site were low compared with other studies (Lashomb et al. 1978, Miller and Stephen 1983, Ross et al. 1990). In 1998, the insecticide applications were discontinued because of low insect infestation in the previous 2 yr. 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 lower if insecticide applications had been made in a manner consistent with previous years. It has been argued that growth losses caused by tip moth infestation are transitory (Williston and Barras 1977); however, this was not yet evident in our 4-yr study. Future growth measurements are intended. Longer-term studies have shown that growth differences as a result of tip moth management are maintained (Cade and Hedden 1987; C.W.B., unpublished data).

This study shows that a variety of insects can be expected to be present, sometimes at damaging levels, in intensively managed loblolly pine stands. Secondary insects, such as pine tortoise scale and mealybugs, may also become important if insecticides that are particularly detrimental to natural enemies are used frequently (Clarke et al. 1990). Intensive management practices may disrupt the balance between common insect pests such as tip moth and their natural enemies. Furthermore, new insect pests, such as coneworms, may become more prevalent as standard management practices intensify.

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