STEM SINUOSITY, TREE SIZE, AND PEST INJURY OF MACHINE-PLANTED TREES WITH AND WITHOUT BENT TAPROOTS: A COMPARISON OF LOBLOLLY AND SLASH PINE[1]

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Abstract—Twenty-four machine-planted stands each of slash (*Pinus elliottii* Engelm.) and loblolly pine (*Pinus taeda* L.) (between ages 3 to 10 years) were randomly selected in the Coastal Plain and Piedmont of Georgia, respectively. Ten points per site were located along a transect and two planted trees within a 10-m radius of each point were selected to best represent high and low levels of stem sinuosity (240 pairs per species). All trees were measured for size, pest injury, and a visual index of stem sinuosity. Three pairs were excavated to characterize taproot shape. When comparing trees with high versus low levels of sinuosity, paired t-tests revealed trees from both species were slightly smaller in size and pest injury was greater for loblolly pine. Levels of stem sinuosity were medium to high for 73 percent and 77 percent of slash and loblolly pine with bent taproots, respectively.

INTRODUCTION

Published research on the planting of southern pines indicates mixed beliefs on the possible long term effects of establishing seedlings with bent taproots. Several studies have found no effect from bent taproots on survival and growth of southern pines (Gruschow 1959, Hay and Woods 1974a and 1974b, Hunter and Maki 1980, Schultz 1973, Woods 1980). Even fewer studies have identified negative effects on the survival and growth of southern pines planted with bent taproots(Harrington and others 1987, Harrington and Howell 1998). Research on other conifer species have shown these same mixed results (Haase and others 1993, Lacaze 1968).

An association was identified for radiata pine (*Pinus radiata* D. Don) in which restricted vertical development of the taproot was associated with stem sinuosity (Balneaves and De La Mare 1989, Mason 1985). Mason (1985) estimated for radiata pine that the number of top quality clear logs produced per hectare could be reduced by up to 36 percent in the presence of high levels of stem sinuosity. After field observations throughout Georgia indicated a possible association between stem sinuosity and the presence of bending in the taproot, we initiated a retrospective study to compare stem sinuosity, tree size, and levels of pest injury of loblolly pine with bent versus straight taproots (Gatch and others [in press]). If reductions in the level of stem sinuosity could be made by modifying planting practices to avoid bending the taproot, such modifications could prove cost-effective due to the potential for large reductions in quality sawtimber crop trees resulting from increased stem sinuosity. Therefore, we designed a follow-up study, similar to that of the loblolly pine study, to investigate slash pine with and without bent taproots. The goal of this paper is to present the slash pine results and compare these with the results from the previous loblolly pine research.

METHODS

Study Sites

For the original loblolly pine study, twenty-four plantations were randomly selected in the Piedmont of Georgia from Conservation Reserve Program plantations. Most of these Piedmont sites have clay subsoil horizons that typically occur at or near the soil surface due to heavy erosion from past agricultural practices (Morris and Campbell 1991). The Conservation Reserve Program (CRP) was a federal program designed to remove a portion of these highly erodible lands from agricultural production by providing financial assistance for reforestation to qualifying landowners. Likewise, twenty-four slash pine plantations were randomly selected in the Coastal Plain of Georgia from lands owned by the Georgia Pacific Corporation and the Union Camp Corporation.

All sites were established through machine planting 1-0 bare-root seedling stock. Selections for both species were stratified such that three plantations were chosen within each of eight, one-year age classes between 3 to 10 years. In the Piedmont, loblolly pine sites were selected so that approximately half of the plantations had received a subsoiling treatment and half had not. In the Coastal Plain, slash pine sites were selected so that one plantation in each age received either a single bedding, single bedding with discing, or a double bedding site preparation treatment. Transects were then established across each plantation with ten sample points located at 20-m intervals.

Vegetation Measurements

All vegetation measurements were conducted from late June to early August 1996 and 1998 for loblolly and slash pine, respectively. A visual index was used for measuring sinuosity that combined the frequency and intensity of stem oscillations into a 0- to 9-point scale (Gatch and others [in press]). This index was used to make estimates of sinuosity on all trees with a 3.59-m radius of each sample point in order to determine the overall level of stem sinuosity for the 24 study sites per species. Branch sinuosity also was estimated for each tree using a similar approach.

A paired-tree sample was used to locate two planted trees within a 10-m radius of each point to represent high and low levels of stem sinuosity (n=240 pairs per species). Each tree

[1] Paper presented at the Tenth Biennial Southern Silvicultural Research Conference, Shreveport, LA, February 16-18, 1999.

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was measured for diameter at breast height (dbh, mm), height (cm), and crown density (percent, after Belanger and Anderson 1992), and visual estimates were made of the level of stem and branch sinuosity. Estimates also were made visually of current year pest injury from fusiform rust (*Cronartium quercum* f. sp. *fusiforme*) branch cankers, Nantucket pine tip moth (*Rhyacionia frustrana* Comstock), and southern pine, black turpentine, and Ips bark beetles (*Dendroctonus* and *Ips* spp.) as a percentage of the bole or crown affected (10 percent classes, after Tallent-Halsell 1994). The presence of fusiform rust stem cankers was avoided during tree selection due to possible stem deformities associated with this injury.

At each site three sample points (usually points three, six, and nine) were excavated for taproot characterization (72 pairs per species). All excavations were performed using hand equipment and were started approximately 1 m from the base of the tree to preserve its root configuration. Excavation was carried to the depth needed to determine the shape of the taproot up to a maximum of 60 cm. Upon extraction, taproot configuration was assigned into one of four categories: straight and single, bent and single, straight and multiple, or bent and multiple. If bending or branching were present then the depth at which the injury occurred was measured (cm). The basal area (m^2/ha) of competing trees was calculated by measuring the dbh (mm) of each tree within 3.59 m of the excavated tree.

Statistical Analysis

All statistical test were performed at the 95 percent significance level using SAS (1989). Paired t-test were used to determine significant difference in dbh, height, crown density, and current year pest injury between high and low levels of sinuosity on the 240 pairs of trees per species. A likelihood ratio chi-square (G) test was used on the 144 excavated trees per species to test the null hypothesis that the frequency of trees with bent versus straight taproots was independent of stem sinuosity index (Sokal and Rohlf 1981). For some cells the frequency of trees with bent versus straight taproots for each value of stem sinuosity index was less than five. To ensure validity of the test (Sokal and Rohlf 1981), stem sinuosity index values were lumped into low, medium, and high values (0 to 2=Low, 3 to 5=Medium, and 6 to 9=High). Analysis of variance (ANOVA) also was used on the data from the 144 excavated trees per species to identify significant differences in size, current year pest injury, and stem and branch sinuosity levels among taproot configurations. In the ANOVA, taproot configuration was specified as a two-by-two factorial design (bent versus straight taproots x single versus multiple taproots), stand was included as a blocking factor, and basal area of competing trees was used as a covariate when significant ($P<0.10$). In order to normalize their distributions, dbh and height were log transformed and all percentage values were converted to proportions and subjected to an arc-sine square root transformation (Snedecor and Cochran 1980). When the interaction term in the ANOVA was significant, multiple comparisons of means were conducted with Bonferroni probabilities (Snedecor and Cochran 1980).

RESULTS

Results of the paired t-test for slash pine revealed that dbh, height, and crown density were 3 percent, 5 percent, and 7 percent smaller, respectively, for trees with high versus low levels of sinuosity ($P<0.02$). Similar results from loblolly pine indicate that trees with high levels of sinuosity were 8 percent, 8 percent, and 14 percent smaller for dbh, height, and crown density, respectively ($P<0.001$). However, where injury from fusiform rust, tip moths, and bark beetles were significantly higher in the presence of high levels of stem sinuosity for loblolly pine ($P<0.05$), no significant differences were found in injury level for slash pine.

For slash pine, only the main effect of bent versus straight taproots was found significant for any response variable in the ANOVA. For loblolly pine, however, not only was the main effect of bent versus straight taproots significant for all response variables, but the main effect of single versus multiple taproots was also found significant for branch sinuosity. Height proved to be the only size variable significantly smaller (9 percent, $P<0.001$) in the presence of taproot bending for slash pine. Though not significant, means for both dbh ($P=0.126$) and crown density ($P=0.076$) were 3 percent smaller in the presence of bent taproots. Dbh, height, and crown density were 9 percent, 7 percent, and 8 percent smaller, respectively, in the presence of bent taproots on loblolly pine ($P<0.01$). Average stem sinuosity index for both loblolly and slash pines with bent taproots was found to be over two to three times greater, respectively, than that of trees with straight taproots ($P<0.001$). Difference in branch sinuosity index were similar, but smaller in magnitude (1.5 to 2 times greater for slash and loblolly, respectively). The only significant response for an injury variable was a slight, but significant increase in tipmoth injury for loblolly pine in the presence of bent taproots ($P=0.009$).

Results of the chi-square (G) test for slash pine ($G=29.3$; $P=0.001$) were similar to those for loblolly pine ($G= 35.3$; $P=0.001$) indicating that the frequency of trees with bent taproots was not independent of stem sinuosity index for either species. Seventy-three percent of slash pine trees with bent taproots had medium to high levels of stem sinuosity (77 percent for loblolly pine), while 78 percent of trees with straight taproots had low levels of stem sinuosity (71 percent for loblolly pine).

Average sinuosity index values of all 24 sites for both species indicated that the overall level of stem sinuosity was medium for both slash (3.2, s.e.=0.05, n=1496) and loblolly pine (2.6, s.e.=0.03, n=1327). A frequency distribution of trees per stem sinuosity index value indicated that 57 percent of slash pine and 49 percent of loblolly pine had medium to high levels of stem sinuosity.

DISCUSSION AND CONCLUSIONS

A comparison of the results of this retrospective analysis of slash pine with the previous research on loblolly pine reveals many similarities. For both species, trees with high levels of stem sinuosity were somewhat smaller in stem size and crown density. An association between high levels of stem sinuosity and higher levels of pest injury was found for loblolly pine, but was not evident for slash pine. After excavation of a subset of trees, presence of bending in the taproot was found to have a significant effect on both slash and loblolly pine. Slash pine height was significantly shorter in the presence of bent taproots while both dbh and crown density were smaller, although these differences were not statistically significant. Similarly, all size variables were significantly smaller in the presence of bent taproots for loblolly pine. In addition to size differences, trees with bent taproots had two to three times the mean value of stem sinuosity index as those with straight taproots. It was found that a large majority of trees for both species with bent taproots (73 percent for slash, 77 percent for loblolly) had medium to high levels of stem sinuosity, while 78 percent and 71 percent of slash and loblolly pines, respectively, with straight taproots had low levels of stem sinuosity.

Results from both southern pine species are quite similar to those found by Balneaves and De La Mare (1989) for radiata pine. Their research indicated that stem sinuosity of radiata pine increased with decreasing depth of subsoiling and penetration and with decreasing straightness of the taproot. Although Balneaves and De La Mare (1989) found no significant differences in tree size with increasing stem sinuosity of radiata pine, our results indicate a similar response in which a small reduction in tree height was detected slash pine and relatively small reductions were found in all size variables for loblolly pine, although differences were statistically significant.

Although the biological mechanism involved in the association between bent taproots and increased stem sinuosity has not been identified, the results of this research indicate an association between the establishment of southern pines with bent taproots and reduced stem quality that may prove to be problematic for land managers. Since a retrospective approach was used in this research and no biological mechanism has been identified, a direct causal link between bent taproots and increased stem sinuosity cannot be inferred. However, these studies indicate a need for further research into the possible mechanisms driving this relationship and a need for research on how modifying planting practices and planting machine specifications could affect the frequency and intensity of taproot bending during planting.

ACKNOWLEDGMENTS

Funding and in-kind support for this study was generously provided by the Georgia Forestry Commission and the USDA Forest Service through the Forest Health Program. Sincere thanks to C. Bridges, T. Clymer, K. Dixon, T. Lowrimore, J. Porterfield, and M. Yates for assisting with field data collection. We thank the landowners of the Conservation Reserve Program, the Georgia Pacific Corporation, and the Union Camp Corporation for the use of their lands.

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