123. Stem sinuosity of loblolly pine seedlings as influenced by taproot shape.
Murphy, M. S. and Harrington, T. B. IN: Proceedings of the 12th biennial southern silvicultural research conference, p. 465-468. USDA Forest Service, Southern Research Station, General Technical Report SRS-71. Kristina F. Connor, ed. 2004.

STEM SINUOSITY OF LOBLOLLY PINE SEEDLINGS AS INFLUENCED BY TAPROOT SHAPE

Michael S. Murphy and Timothy B. Harrington[1]

Abstract—Sinuous stem growth in loblolly pine (*Pinus taeda* L.) results in diminished potential for the utilization of wood products since these stems are difficult to mill and contain a higher percentage of compression wood. In this study, 90 full-sibling loblolly pine seedlings (30 seedlings from each of 3 families) were planted with 5 taproot configurations: straight taproot (check treatment), straight taproot with underground obstruction, taproot planted with "J" shape, straight taproot planted at a 45 degree angle, and a straight taproot with the stem guy-wired to a 45 degree angle. Seedlings were irrigated and fertilized to maintain high growth rates, and insect control treatments were applied to minimize injury from the Nantucket pine shoot tip moth (*Rhyacionia frustrana* Comstock). Growth and form data were collected after the first growing season. Statistical analyses were conducted to determine if seedling growth rate and stem eccentricity varied significantly according to family, taproot treatment, or their interaction.

INTRODUCTION

Sinuous stem growth, an oscillating curvature of the stem, may be caused by taproot deformity. Sinuous trees contain more compression wood, which is one of the mechanisms in gymnosperms responsible for stem curvature. However, compression wood is undesirable for wood utilization purposes. It comprises 10–15 percent of wood volume in southern pines (Timell 1986) and results in warping of lumber, which has less strength under tension, creating a product that may endanger life and property (Koch and others 1990). It is also undesirable for pulpwood utilization because of its high lignin and low cellulose contents, leading to reduced pulp yield and quality (Low 1964). If it can be determined that taproot deformity is a cause of stem sinuosity, alternative planting procedures could be developed to reduce compression wood formation.

Compression wood corrects a bent stem to its normal position by longitudinal expansion on the concave side of the stem. Sinuosity is a result of an overcorrection, when the stem is bent back into a bend in the opposite direction (Timell 1986). This series of oscillating curves continues up the stem until equilibrium is reached and normal growth resumes. Sinuous condition usually remains for the life of the tree. Although the exact mechanism is unknown, gravitational stimulus is commonly accepted as a cause of compression wood formation (Koch and others 1990, Sinnott 1952). However, recent research has shown that compression wood can form in the microgravity environment of the NASA space shuttle (Kwon and others 2001).

Planting methods that result in compressed and/or bent lateral roots and taproots are a suspected cause of stem sinuosity (Harrington and others 1999). The presence of a soil hardpan can mimic these conditions by providing an impenetrable obstruction resulting in taproot bending. Balneaves and De La Mare (1989) compared tree growth and root development in soils with a known mineral hardpan. Treatments consisted of ripping the soils to varying depths and no ripping. Greater taproot penetration was found on the ripped sites when compared to unripped sites. The least amount of stem deviation was found on those sites with the straightest and deepest penetration of taproots.

Conversely, other studies indicate root deformation has no negative effects on survival and growth. Although the problems of compression wood and stem sinuosity were not addressed directly in these cases, these studies show that early growth is greater for trees with deformed root systems (Hay and Woods 1974a, 1974b, Seiler and others 1990, Woods 1980). This may occur because deformed roots develop more lateral roots near the soil surface, and these laterals are more important than deep taproots for absorbing limited soil moisture during dry periods (Hay and Woods 1974b). Deformed roots also may improve wind resistance due to their increased upper lateral root growth (Hunter and Maki 1980, Seiler and others 1990). They could, however, hinder later growth because as deformed roots grow in their twisted condition some break and die, making the tree more susceptible to windfall, insects, and disease (Hay and Woods 1974a).

Although the majority of the literature assumes that root deformity has no negative effect on growth and survival, few researchers have addressed the problem of stem form in association with root deformity. Harrington and others (1999) performed a retrospective study on machine planted loblolly pine to assess the relationship between stem sinuosity and root deformation. Trees identified as having sinuous characteristics were assigned to an index that correlated with their degree of sinuosity. These trees were then excavated and their root systems examined. The results indicated a potential correlation between bent taproots and reduced stem quality. This study's objective is to show a relationship between sinuous stem growth and taproot deformation in newly planted seedlings.

[1] Research Coordinator, D.B. Warnell School of Forest Resources, University of Georgia, Athens, GA 30602-2152; and Research Forester, USDA Forest Service, Pacific Northwest Research Station, 3625 93rd Avenue SW, Olympia, WA 98512-9193, respectively.

Citation for proceedings: Connor, Kristina F., ed. 2004. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 594 p.

MATERIALS AND METHODS

Study Site Description

This study was located at Whitehall forest in Athens, GA. Development of planted pine seedlings was studied both in raised beds and in an open field. Both the beds and the field were tilled to a 30-cm depth prior to planting. Competing vegetation was controlled using glyphosate herbicide. The bare mineral soil was mulched with pine straw to maintain soil tilth and suppress development of competing vegetation. Seedlings were irrigated throughout the growing season with soaker hoses and fertilized with macro- and micronutrients.

Study Design

The experimental design of the study is a randomized complete block with a factorial arrangement of treatments. Five taproot treatments were applied to three full-sibling families. The taproot treatments included a straight taproot/straight stem planting (check treatment), a straight taproot with obstruction planting, a j-root planting, an angled taproot/stem planting, and a straight taproot/angled stem planting. The three full-sibling families were selected for their stem straightness characteristics. Each combination of the 5 taproot treatments and 3 families was replicated 6 times, resulting in a total of 90 seedlings. Treatment replications were grouped in blocks, and three blocks each occurred in the raised beds and in the field.

An effort was made to create identical soil disturbance conditions for each taproot treatment. The taproot obstruction required the use of a 45-cm x 45-cm plexiglass sheet. A square area was excavated and the plexiglass was placed at a depth of 20 cm. This same large excavation was done for each planting. The angled planting was done by holding the entire tree at a 45 degree angle as soil was filled around it. The straight taproot/angled planting was done by planting the tree with a straight taproot. The tree stem was then pulled over to a 45 degree angle with a wire and maintained in that position by securing the wire to a stake.

Measurements

Measurements of stem diameter (at 1 cm above ground), height, and frequency and amplitude of stem curvature were collected on October 8, 2002, one growing season after planting. Frequency of stem curvature was determined as the number of interwhorl curves that occurred in the main stem. Amplitude of stem curvature was measured as the distance from the peak of each stem curve and a vertically held straight edge. These values were averaged for the entire stem of each tree.

Statistical Analysis

The variables of stem diameter, height, frequency, and amplitude were subjected to analysis of variance to determine if tree size and stem curvature varied significantly ($\alpha = 0.05$) among taproot treatments, families, or their interactions. Multiple comparisons of treatment means were conducted with Tukey's test. All analyses were performed with SAS (SAS Institute 1989).

RESULTS AND DISCUSSION

Taproot Treatment

Stem diameter and frequency of stem curvature varied significantly among taproot treatments while height and amplitude did not (table 1). Seedlings planted with a "J" shaped root had the smallest values for stem diameter. Frequency was greater for the treatments which had a higher diameter (fig. 1). In general, the largest seedlings had the greatest frequency of stem curvature.

Family

Stem diameter, height, frequency, and amplitude of stem curvature each varied significantly among families. Family (A) significantly outgrew the other families in height. This growth likely affected frequency, resulting in a significant difference in family (A) from the other families (fig. 2). It is difficult to say if the expression of sinuous characteristics is a result of the increased growth of family (A) or a symptom of the genetic characteristics of this family. As with treatment, measurements collected during the second growing season may provide clarification.

Interaction Effects

While significant differences existed among taproot treatments and families, there were no significant treatment interactions.

CONCLUSIONS

The preliminary data collected during the first growing season indicate some differential growth responses to taproot treatment and family. In general, seedlings with greater growth had more pronounced levels of stem sinuosity. By comparing tree responses among the taproot treatments we hope to identify planting or planting spot characteristics that are associated with increased levels of stem sinuosity. Seedling growth and sinuosity responses will be monitored for a second growing season. In addition,

Table 1—Significance levels for the effects of taproot treatment, family, block, and their interaction. Factors are considered significant if $P \leq 0.05$

Variable	Treatment	Family	Interaction	Block
Diameter	0.0382	0.0081	0.8548	0.8682
Height	0.5778	0.0003	0.9863	0.9608
Frequency	0.0122	< 0.0001	0.0977	0.1986
Amplitude	0.1121	0.0035	0.2352	0.0447

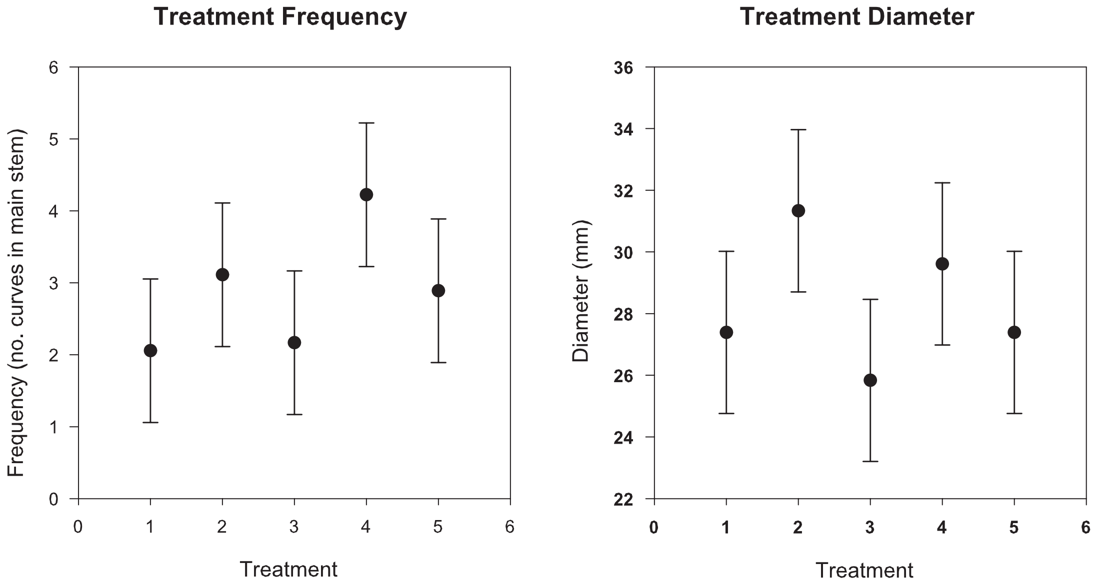

Figure 1—Comparisons of taproot treatment means, with 95 percent confidence intervals for frequency and diameter. Taproot treatments are 1-check (straight taproot, straight stem), 2-taproot obstruction, 3-J-root treatment, 4-angled planting, 5-straight taproot, stem angled.

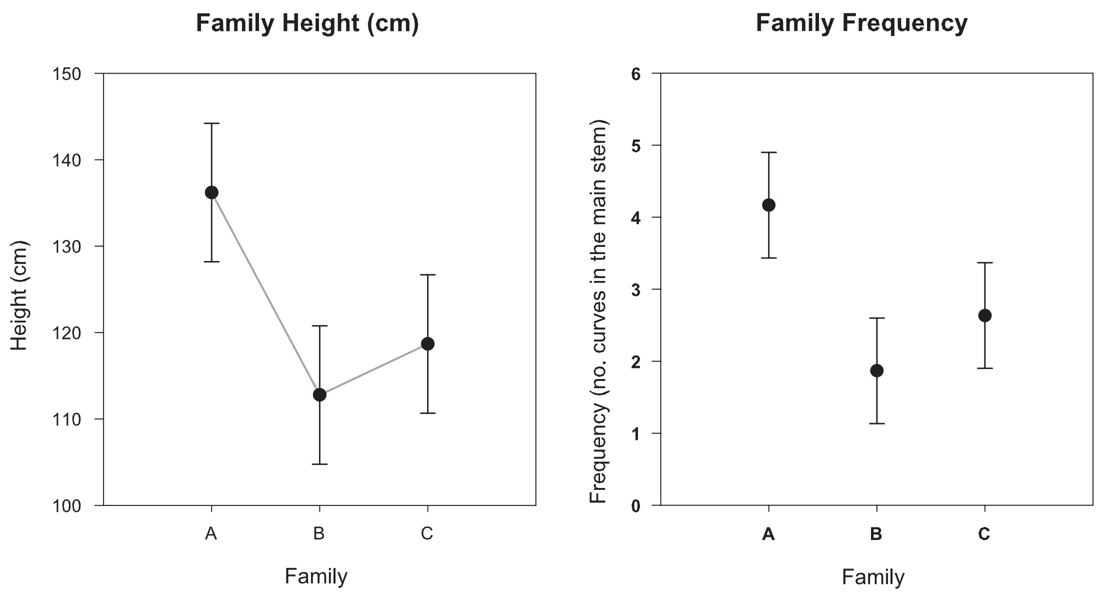

Figure 2—Comparisons of family means, with 95 percent confidence intervals for frequency, and height.

trees will be harvested and evaluated for different wood properties among the treatments.

Ongoing measurements in existing field studies also are underway. Specifically, data are being collected in 6-year old plantations that have straight, "J", and "L" shaped taproot plantings. Three of these plantations are comprised of loblolly pine and three are slash pine (*Pinus elliotti*). To determine if tree responses are influenced by availability of belowground resources, plots for each planting treatment are split with half receiving N+P fertilization and herbaceous weed control and half receiving neither of these treatments. As in the seedling study, stem diameter, height and the frequency and amplitude of stem curvature are being collected on these trees.

ACKNOWLEDGMENTS

We would like to thank Mike Hunter and Dale Porterfield of Whitehall Forest for providing the facilities and assistance. We would also like to thank Terry Price of the Georgia Forestry Commission for initiating the idea behind this experiment. Thanks to Mike Cunningham of International Paper for providing the full-sibling seedlings. Finally, we would like to thank Richard Daniels, Laurie Schimleck, Mike Huffman, Gopal Ahuja, and Doug Marshall for their assistance.

LITERATURE CITED

Balneaves, J.M.; De La Mare, P.J. 1989. Root patterns of *Pinus radiata* on five ripping treatments in a Canterbury forest. New Zealand Journal of Forest Science. 19(1): 29-40.

Harrington, T.B.; Gatch, J.A.; Price, T.S. 1999. Stem sinuosity, tree size, and pest injury of machine-planted loblolly pine with bent versus straight taproots. Southern Journal of Applied Forestry. 23: 197-202.

Hay, R.L.; Woods, F.W. 1974a. Root deformation correlated with sapling size for loblolly pine. Journal of Forestry. 72: 143-145.

Hay, R.L.; Woods, F.W. 1974b. Shape of root systems influences survival and growth of loblolly pine seedlings. Tree Planter's Notes. 25(3): 1-2.

Hunter, S.C.; Maki, T.E. 1980. The effects of root curling on loblolly pine. Southern Journal of Applied Forestry. 4: 45-48.

Koch, P.W.; Cote, W.A., Jr.; Schlieter, J.; Day, A.C. 1990. Incidence of compression wood and stem eccentricity in lodgepole pine of North America. Res. Pap 420. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 40 p.

Kwon, M.; Bedgar, D.L.; Piastuch, W. [and others]. 2001. Induced compression wood formation in Douglas fir (*Pseudotsga menziesii*) in microgravity. Phytochemistry. 57: 847-857.

Low, A.J. 1964. A study of compression wood in Scots pine (*Pinus silvestris* L.). Forestry. 37: 179-201.

SAS Institute, Inc. 1989. SAS/STAT User's guide. Version 6. vol. 2. 4th ed. Cary, NC: SAS Institute, Inc. 1686 p.

Seiler, J.R.; Paganelli, D.J.; Cazell, B.H. 1990. Growth and water potential of j-rooted loblolly and eastern white pine seedlings over three growing seasons. New Forests. 4: 147-153.

Sinott, E.W. 1952. Reaction wood and the regulation of tree form. American Journal of Botany. 39: 69-78.

Timell, T.E. 1986. Compression wood in gymnosperms. Vol. 2. Berlin, Germany: Springer-Verlag: 707-1338.

Woods, F.W. 1980. Growth of loblolly pine with roots planted in five configurations. Southern Journal of Applied Forestry. 4: 70-73.

Proceedings of the 12th biennial southern silvicultural research conference

Author(s): Connor, Kristina F., ed.

Date: 2004

Source: Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 600 p.

Station ID: GTR-SRS-071

Description: Ninety-two papers and thirty-six poster summaries address a range of issues affecting southern forests. Papers are grouped in 15 sessions that include wildlife ecology; fire ecology; natural pine management; forest health; growth and yield; upland hardwoods - natural regeneration; hardwood intermediate treatments; longleaf pine; pine plantation silviculture; site amelioration and productivity; pine nutrition; pine planting, stocking, spacing; ecophysiology; bottomland hardwoods - natural regeneration; and bottomland hardwoods—artificial regeneration.