METHODOLOGY AND PRELIMINARY RESULTS OF EVALUATING STEM DISPLACEMENT AND ASSESSING ROOT SYSTEM ARCHITECTURE OF LONGLEAF PINE SAPLINGS

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ABSTRACT

A field experiment of the effects of container cavity size and root pruning type on longleaf pine was established in November, 2004, in central Louisiana. Sapling stems were first observed to be leaning after hurricane Gustav (September, 2008) and again in August, 2009. To examine the relationship between stem displacement and root system architecture, a stem-displaced longleaf pine (sapling was paired with a nearby, non-displaced sapling of comparable size in each of the 24 treatment plots of the original experiment. Saplings were excavated in May, 2010. Here we report the methodology and preliminary results of evaluating stem displacement and assessing root system architecture in three additional longleaf pine saplings in the same experiment. One sapling became toppled in February 2010; the second sapling was toppled by wild horses in August 2009; and the third was a non-displaced sapling which was knocked down during excavation.

INTRODUCTION

Most of the natural longleaf pine (*Pinus palustris* Mill.) forests and ecosystems were decimated by excessive logging between the late 1800s and the early 1900s. Some of these areas were eventually regenerated to fast-growing loblolly pine (*P. taeda* L.) and slash pine (*P. elliottii* Englem.) forests or cleared for cropland or pasture (Landers and others 1995). Much of the original longleaf pine range is within 240 km of the Atlantic or Gulf coasts, a region frequented by strong tropical wind storms including hurricanes (Landers and others 1995). Longleaf pine trees suffered less wind damage than loblolly pine after hurricanes Hugo (September, 1989) in South Carolina (Gresham and others 1991) and Katrina (August, 2005) in Mississippi (Johnsen and others 2009). With increasing occurrence of hurricanes in the Atlantic and Gulf States in recent decades, many forest managers and landowners have decided to restore longleaf pine over these hurricane-prone, historical longleaf pine areas.

More than 70 percent of the longleaf pine seedlings produced by nurseries in the southern United States were container stock for the 2005-2006 planting season (McNabb and Enebak 2008). About 90 percent of the longleaf pine seedlings planted in 2008 were from container stock (Barnard and Mayfield 2009). This trend of preference for longleaf pine container stock continues to date. Container-grown longleaf pine seedlings generally had greater first year field survival than bareroot seedlings (South and others 2005 and references cited therein). However, between the age of 5 and 10 years, juvenile stem instability, such as leaning, bending, and toppling, occurred after high winds mostly in the container stock longleaf pine saplings and not in the bareroot saplings (South and others 2001).

After Hurricane Gustav (September, 2008), sapling leaning was observed in a container stock longleaf pine field experiment established in November, 2004. More sapling stem displacement was sighted in the same study in August, 2009. We hypothesized that root system architecture is the main factor for longleaf pine sapling stem instability. Here we report the methodology and preliminary results of evaluating stem displacement and assessing various parameters pertaining to the root system architecture. The objectives of the study are to 1) compare root system architecture and stem wood quality of stem-displaced (SD) longleaf pine saplings with that of the non-displaced (ND) saplings and 2) assess effects of container size and root pruning type on sapling instability and root system architecture.

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MATERIALS AND METHODS

SEEDLING CULTURE AND FIELD ESTABLISHMENT IN THE ORIGINAL STUDY

Details of seedling culture and field establishment protocols were reported by Sword Sayer and others (2009). Briefly, LLP seeds of mixed seedlots from Florida were sown in containers of three cavity sizes and two cavity coating types in April, 2004. Container cavity volumes for the small, medium, and large cavity sizes were 54, 93, and 170 ml, respectively. Styroblock ® and Copperblock® containers (Beaver Plastics Ltd, Edmonton, Alberta, Canada) of the above mentioned cavity sizes were used for no copper root pruning and copper oxychloride root pruning treatments, respectively. Seedling culture protocols were adapted from those by Barnett and McGilvray (2000) with some modifications (Sword Sayer and others 2009).

The field experiment site is located on the Palustris Experimental Forest within the Kisatchie National Forest in Rapides Parish of central Louisiana (N 31°11', W 92°41'). The soil is a moderately well-drained, gently sloping Beauregard silt loam (fine silty, siliceous, superactive, thermic, Plinthaquic Paludults). Mima mounds of Malbis fine sandy loam (fine loamy, siliceous, subactive, thermic, Plinthic Paleudults) are scattered across the study area. It is a 2 by 3 randomized complete block factorial design with four replications. Twenty-four (3 cavity size x 2 root pruning type x 4 blocks) treatment plots of 0.0576 hectare (24 m x 24 m) each were established. In early November, 2004, 27-week-old container-grown LLP seedlings were lifted and planted on the same day. Seedlings were planted at 2 m x 2 m spacing. Treatment plots are 12 rows of 12 trees. All plots were prescribed burned in February, 2006 (15 months post planting) and again in May, 2009.

SAPLING SELECTION AND ROOT EXCAVATION

In December 2009, all longleaf pine saplings in the original field experiment were assessed visually for stem displacement. In May 2010, a pair of saplings from each of the 24 treatment plots was selected for root excavation. One stem-displaced (SD) sapling was randomly selected from each plot and a non-displaced (ND) sapling of comparable size was selected within a 6-m distance of the selected SD sapling. All fascicles were collected before the north and east sides of the sapling stems were marked with paint starting at the ground level. For the stem displacement evaluation, each sapling was photographed from the side that best illustrated the greatest stem displacement. A vertical height (HT) pole was placed at the ground line of each stem for scaling and alignment. These photographs were used to calculate sinuosity index (SI) and to design a numerical system of ranking stem displacement in the field. Saplings were then cut at ground level. A metal tag was nailed to the north side of the stump. A spade was used to cut along the edge of a 1 m x 1 m square centered on the stump before the root system was excavated with a track hoe. The excavation followed the entire length of the taproot or sinkers. Soil was washed off the root systems before root architecture assessment.

Stem length (tracing along the shape of the stem from the ground line to shoot tip), HT (vertical distance between the ground line and the highest point of the sapling before cutting), diameters at breast height (at 140 cm along the stem length from the ground line, DBH) and at ground line were measured. Three stem segments of 15 cm each were cut with the centers of each of the three segments located at 30, 100, and 140 cm from the ground line up along the length of the stem. These segments were immediately stored in plastic bags on ice. The rest of the stem and branches were also collected. All sapling components were oven dried at 70 C in a forced-air oven except for the stem segments.

DENSITOMETRY

All stem segments were oven dried at 50 C in a forced-air oven for 1 week. From each stem segment, wood specimens for densitometry were obtained by cutting 12 mm x 12 mm sections from bark to bark, and encompassing the pith. Two densitometry specimens were prepared from each tree segment to allow the collection of densitometry data from bark to pith in four compass directions; north, south, east, and west. Specimens were glued (Gorilla Glue, Cincinnati, OH) into yellow-poplar core holders, dried under ambient conditions, and then sawn into 2.3 mm thick strips, from bark to bark, and through the middle of the pith with the radial surface exposed, bordered by strips of yellow-poplar wood. Densitometry was performed using a Quintek Measurement Systems (Knoxville, TN) X-ray densitometer with a resolution of 0.00001. Specific gravity measurements were determined at 0.06 mm intervals. Specific gravity is the ratio of the density of wood (oven dry weight/green volume) to the density of water at 4 C, 1.0 g/cubic cm. A specific gravity value of 0.480 was used to differentiate between earlywood and latewood zones for each core.

ROOT SYSTEM ARCHITECTURE ASSESSMENT

Root system architecture was assessed by placing the stump upside down on the center of a round board with a diameter of 1 m and twelve 30-degree segments. Any portion of the first-order lateral roots (FOLRs) that extended beyond the edge of the board was trimmed off. A FOLR is the primary lateral root originating from the taproot and has at least 0.8 cm diameter measured at 1 cm from the taproot. Parameters on taproots, sinker roots, adventitious roots, and FOLRs were assessed. After the assessment, FOLRs with their branches, sinkers, and adventitious roots were trimmed off the taproot. All root system components were oven dried at 70 C in a forced-air oven.

METHODOLOGY, PRELIMINARY RESULTS, AND DISCUSSION

STEM DISPLACEMENT EVALUATION

Stem displacement was evaluated objectively and subjectively. For the objective evaluation, the SI was measured digitally from the photographs taken in the field according to the procedures by Leduc and others (current Proceedings). The SI is derived from dividing a smallest possible rectangular area encompassing the entire main stem (and not necessarily all the branches) by HT (cm) x DBH (cm). Among various ways of deriving sinuosity indices, this one was recommended by Leduc and others (current Proceedings). Based on the photographs, a qualitative stem displacement (QSD) scale of 0 to 5 (fig 1a) was designed to subjectively evaluate stem displacement in field. A straight or ND stem has a QSD value of 0 and the QSD value for a toppled stem is 5. Figure 1b presented a qualitative scale of ranking the extent of displacement recovery by a SD stem. This scale was based on the study of Cremer (1998) and our field observations. According to Cremer (1998), stem creep (scale = 4.5, fig 1b) occurred when the combined weights of a displaced stem and its branches and fascicles would push previously displaced stem further toward the ground level. Creep reversal (scale = 3 to 4, fig 1b) described the extent of stem recovery from a creep condition. Stems with a curved lean or various degrees of sinuosity are the results of recovery from displacement (fig 1b, Cremer 1998). It should be noted that unless one visits the field often, one may not be able to distinguish between stem displacement and recovery. To solve this issue, QSD scales in figures 1a and 1b should be used simultaneously in a field evaluation. Although objective, a SI system still does not distinguish between stem displacement and recovery.

Table 1 presented some preliminary results of this study. A SD sapling which toppled in February, 2010 (Feb-SD) had a rectangular area based SI of 49.5 and a QSD scale of 3.5. Another SD sapling (Horse-SD), whose displacement was probably the result of wild horses straddling in August, 2009, had an SI of 56.2 and a QSD scale of 3.0 in May, 2010. This sapling had SI of 79.7 and 65.4 and QSD of 4.5 and 4.0 in August, 2009 and January, 2010 respectively. Based on its QSD values over time, this horse-SD sapling was recovering from displacement after August, 2009. Although decreasing over the same period of time, the final SI was still high for this sapling. The ND sapling in table 1 was accidently knocked down by the track hoe during excavation. This sapling had an SI of 4.3 and a QSD scale of 0.0 before the accident.

DENSITOMETRY

We hypothesized that stem wood quality, such as latewood percents and presence of compression wood, as delineated by stem segment densitometry, is the result of stem displacement not the cause. A specific gravity of 0.480 for southern pines was used to distinguish between earlywood and latewood. Presence of higher density compression wood in some of the specimens was unavoidably counted as being latewood. However, because these saplings were cut in May, 2010, the outermost growth ring in each specimen can only be early wood. Both SD saplings in table 1 had greater 2010 early wood densities than the ND sapling. The Feb-SD sapling which was toppled in February, 2010 had similar wood density for the 2009 growth ring to that of the ND and both were lower than that of the horse-SD sapling. No differences in densities existed in the 2008 growth rings for all three saplings which were straight in 2008.

ROOT SYSTEM ARCHITECTURE ASSESSMENT

Rationale and methods of assessing root system architecture in LLP saplings are described below.

Taproots--One advantage that the naturally regenerated LLP seedlings have over the artificially regenerated LLP seedlings is root system architecture. The readily distinguished feature of the former is a long taproot. Taproot length of container LLP, however, is limited by the container cavity depth. Cavities of 10 to 15 cm depth are generally used to grow LLP seedlings in commercial nurseries in the South (Barnett and McGilvray 2000). Taproot is critical to the vertical anchorage of young trees (Burdett and others1986). Because container seedling root plug does not allow pre-outplanting seedling culling based on its root system, some toppled LLP saplings were found to have a much shorter taproot length than the cavity depth (Sung and others 2009). The ND sapling in table 1 was lightly bumped by the track hoe but it toppled immediately. Its taproot extended only 6.5 cm into the soil and had 3.6 percent of total sapling dry weight (DW). Although this sapling was straight before the incident, its lack of vertical anchorage by taproot or sinker roots probably was the cause of toppling by a gentle bump from the track hoe. The horse-SD sapling had similar taproot rooting depth and DW allocation percentage to those of the ND sapling. Compared to the ND or horse-SD saplings, the Feb-SD sapling had much greater taproot rooting depth and DW allocation percentage (table 1). Apparently, the vertical anchorage provided by its deep rooting taproot of substantial mass did not prevent the sapling from toppling. Had it not been sampled, this Feb-SD probably would have eventually recovered because of its deep taproot.

Sinker roots and adventitious roots--After seedlings are outplanted and become in contact with soil moisture, callus tissues will form at the air-pruned end of the container seedling taproot. From these callus tissues, adventitious roots will originate and extend. Sinker roots are adventitious roots which extend vertically (greater than 135 degrees from the taproot) downward into the soil. Some adventitious roots would extend horizontally (about 90 degrees from the taproot) or slightly oblique (less than 135 degrees from the taproot). Depending on the local soil strength or conditions which may be preexisting or caused by planting technique, adventitious roots may or may not extend vertically downward and become a sinker. We hypothesized that sinker roots with large diameters and deep extension into the soil can also offer vertical anchorage to LLP saplings. The horse-SD sapling recovered from a QSD value of 4.5 in August, 2009 to 3.0 in May, 2010. One sinker reached to the depth of 66.5 cm and may have provided the vertical support for stem recovery. Cremer (1998) reported the elongating zone of a displaced P. radiata stem can right itself within a week. But it may take trees of 1.5 to 2 m tall up to 16 months for the stem to become upright and another 2 or 3 years to correct the buttsweep which could compromise wood quality. He did not report on the root systems of these trees.

First-order lateral roots--Number of FOLR was reported to be a highly heritable trait in loblolly pine (Kormanik and others 1990). Copper root pruning treatment affected FOLR egress depth one year after outplanting (Sword Sayer and others 2009). Seedlings grown in copper cavities have similar percents of FOLR egress from each third zone of the original root plug whereas seedlings grown in regular, non-copper cavities had the highest percent of FOLR egress from the bottom third region or the end of root plug (Sword Sayer and others 2009). In this study, FOLR egress depth in soil profile was determined by measuring the vertical distance between the cut stump surface and the beginning portion of a FOLR that was clearly extending away from the taproot circumference. Lengths of the portions of FOLRs extending vertically or horizontally or obliquely close to the circumference of a taproot indicate the extent of FOLR spiraling or strangulation. Number of 30-degree segments a FOLR crosses and number of 30-degree segments that do not have any FOLR crosses may indicate the evenness of FOLR egress around the circumference of taproots. It is obvious that if all FOLR of a LLP sapling egress into one direction (for example, a contiguous three 30-degree segments) or two opposite directions (such as in a plane root system), this LLP may also topple into the leeward direction of high winds. Although FOLR egress evenness was similar among the three saplings in table 1, the Feb-SD sapling which was from non-copper cavities had greater extent of FOLR spiraling than the other two non-copper saplings (6 cm versus less than 3 cm, table 1)

CONCLUSIONS

We designed a detailed assessment scheme for root system architecture evaluation in hoping to be able to correlate sapling stem displacement to one or several root parameters. Our preliminary results showed promising association between sapling stem displacement and taproot and sinker depths in the soil profile. With increasing number of longleaf pine seedlings used for artificial regeneration being container stock, the risk of sapling mechanical instability caused by high winds, ice storm, or animals cannot be overlooked.

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Table 1—Examples of stem displacement, growth, wood density, and root system architecture in two stem-displaced (SD) and one non-displaced (ND) longleaf pine saplings excavated during the sixth growing season. The Feb-SD sapling was toppled in February, 2010; the horse-SD was bent by wild horses in August, 2009; and the ND sapling was straight before it was knocked down by a track hoe during excavation in May, 2010

	Feb-SD	Horse-SD	ND*
Sinuosity Index	49.5	56.2	4.3
Qualitative Stem Displacement Scale	3.5	3.0	0
Height (cm)	122	226	365
Stem Length (cm)	267	379	365
Diameter at Breast Height (cm)	3.63	4.14	4.08
Ground Line Diameter (Dia) (cm)	6.85	7.88	4.60
2010 Earlywood Density (kg/m^3)	397	430	335
2009 Earlywood Density (kg/m^3)	344	310	343
2009 Growth Ring Wood Density (kg/m^3)	401	460	408
2008 Earlywood Density (kg/m^3)	328	338	341
2008 Growth Ring Wood Density (Kg/m^3)	339	366	355
Total Sapling Dry Weight (kg)	3.41	4.78	4.80
Taproot DW Allocation (%)	9.0	3.0	3.6
Sinker Root DW Allocation (%)	0	5.8	0
Adventitious (Adv) Root DW Allocation (%)	0	3.9	9.3
First-Order Lateral Root (FOLR) DW Allocation (%)	10.2	10.2	9.0
Sinker Root (#)	0	2	0
Adv Root (#)	0	2	3
FOLR (#)	9	9	7
Rooting Depth of Taproot (cm)	55.0	6.5	6.5
Taproot Dia @ 5 cm from the Ground Line (cm)	6.60	8.12	7.81
Rooting Depth of Largest Dia Sinker Root (cm)	0	66.5	0
Rooting Depth of Largest Dia Adv Root (cm)	0	2.0	1.5
% FOLR Originating Zone on Taproot			
0 - 5 cm	44	22	57
5.1 - 10 cm	56	78	43
10.1 – root plug end	0	0	0
% FOLR Egress into Soil Profile			
0 - 5 cm	44	22	43
5.1 - 10 cm	44	78	57
10.1 – root plug end	11	0	0
> root plug end	0	0	0
Mean FOLR Dia (cm)	1.40	1.49	2.18
Mean FOLR Spiraling Length (cm)	6.1	2.4	2.9
Mean 30-Degree Segments FOLR Crossing (#)	3.9	2.8	3.0
30-Degree Segments without FOLR Egress (#)	5	7	6

*Values for sinuosity index, qualitative stem displacement scale, and height for this ND sapling wereobtained by propping the sapling up.

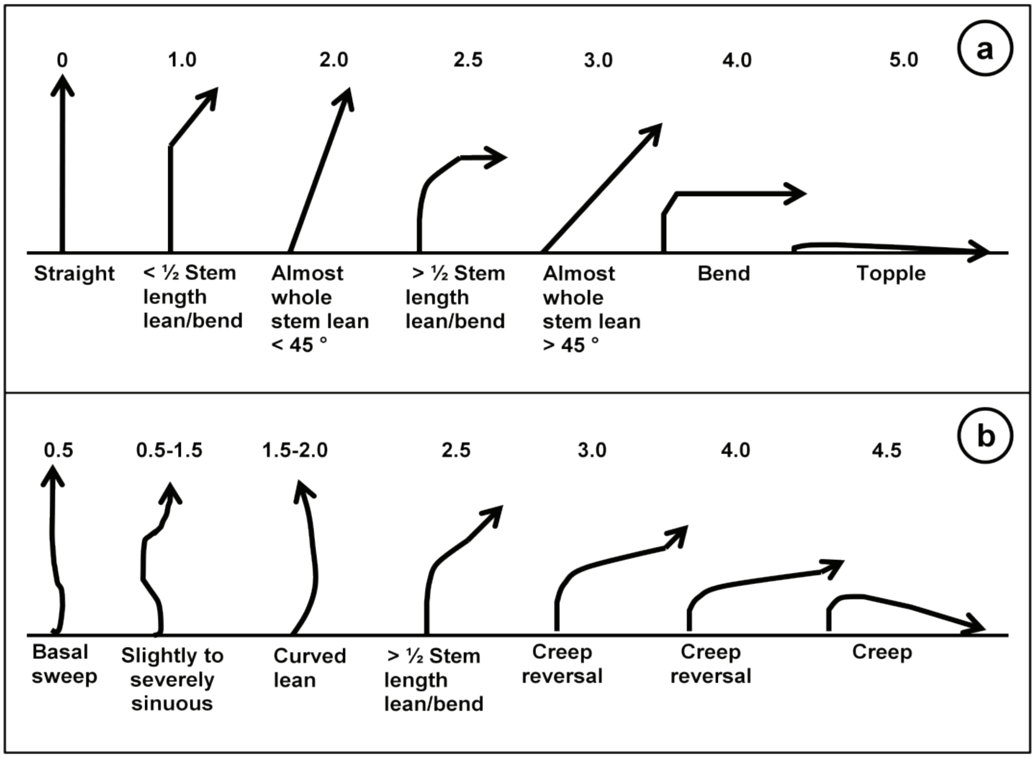

Figure 1—(a) Stem displacement scale of 0, straight to 5, topple; (b) scale of stem recovery from displacement with 0.5 for basal sweep and slightly sinuous and 4 for creep reversal. Creep (4.5) occurs when stem displaces further toward the ground due to its own weight.