BREAST LEVEL HEIGHT DISPLACEMENT: DO STANDING TREES SINK INTO THE SOIL

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ABSTRACT

Increases in the above-ground biomass (bole, crown) may result in trees sinking due to gravity and the corresponding decrease in the original diameter at breast height (d.b.h.) level, further referred to as displacement. Below-ground increases in biomass (roots) push the soil up and out and may result in raising the ground level. Both forces may be at work and partially offset one another. These phenomena may produce errors when estimating volume as a function of d.b.h. Remeasuring diameter at the same level across time removes this complication. Lines placed at d.b.h. at age 12 and periodically remarked in a 43-year-old pine (*Pinus taeda* L.) plantation are lower than 4.5 feet above the ground level, especially for larger trees. The objective of this study is to determine whether the d.b.h level of loblolly pine trees at 43 years of age have changed because of displacement and/or ground-raising.

There is some force that has caused these trees to rise over time from ground level at the time of planting, most likely roots pushing the tree up because of a high clay content which provides resistance to root expansion. Part of this soil "rise" around trees is offset by the tree sinking due to weight. To prevent volume estimation errors, d.b.h. should be permanently marked during the establishment of research studies.

INTRODUCTION

Forest research is vital to obtain optimal operational management scenarios. Often, research is conducted on a limited number of individuals and then information from this sample is used to infer about the behavior of the population as a whole. Therefore, it is important to obtain accurate measurements during research operations and to understand all aspects of processes that may ultimately be used when making management decisions. Growth and yield models are a tool regularly used to produce optimal management scenarios. It is imperative that the data used to develop these systems are accurately and consistently measured across time. One important measurement is the diameter at breast height (d.b.h.) level which in the United States is 4.5 feet above the ground line.

As trees grow, their weight and size increases. It is known that as the above-ground component of a tree becomes larger so does its root volume (Kapeluck and Van Lear 1995, Pehl and others 1984). An increase in the above-ground biomass of a tree (bole, crown) may result in the tree sinking due to gravity and the corresponding decrease in the original breast height level, further referred to as displacement. Below-ground increases in biomass (roots) push the soil up and out and may result in raising the ground level. It is our belief that both forces may be at work and to some extent offset one another. These forces likely differ among sites depending upon factors such as soil type, slope, climate, perhaps even due to the presence or lack thereof of fragipans, etc, and likely among species, stand densities, and even factors such as genetics (e.g., crown structure and density, wood density, and so forth), and other factors. Displacement and ground-raising may increase for larger trees since their above-ground weights and root volumes are greater.

These phenomena may result in errors when estimating volume. Perhaps there are several ways, but we believe one way is that displacement and ground-raising can impact the d.b.h. level over time, and hence the measurement of d.b.h. that is often used to produce volume (weight or biomass, etc.) estimates. Remeasuring diameter at the same level across time removes this complication. If the d.b.h. line is not marked at the time of study establishment, volumes and diameter increments will be underestimated. We noticed that lines (stripe of white paint) initially placed at age 12 and periodically remarked on trees in a 43-year-old loblolly pine (*Pinus taeda* L.) plantation in southeastern Arkansas are lower than 4.5 feet above the ground level, especially for larger trees (and subsequently in the unthinned portion of the study as well). To document this minor process of stand dynamics and explain it, we conducted the following investigation.

The objective of this study is to determine whether the d.b.h. level of loblolly pine trees at 43 years of age has changed because of displacement and/or ground-raising.

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Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station.262 p. https://doi.org/10.2737/SRS-GTR-268.

METHODS

Hypotheses

To find an explanation of the observed change in the diameter at breast-height level, referred to as displacement, we formulated these four hypotheses:

1. Sinking due to gravity caused by an increase in the above-ground biomass of a tree
2. Ground elevation resulting from the increase of below-ground volume of roots, which pushes the soil out and up
3. Combination of these two forces
4. The extent of both forces is related to tree weight and volume

Approach

The measurements of displacement, D, and ground elevation increase, G, are sufficient to test these hypotheses. We assumed no error during the initial establishment of d.b.h. at age 12 (and at age 27 for the unthinned portion). There are two apparent cases:

1. D = G. This would mean that the sole reason for displacement is ground elevation.
2. D > G. In this case the tree sank into the soil.

Monticello Thinning and Pruning Study

The stand was established in the winter of 1958-1959 in a row-cropped old field at a spacing of 8 feet by 8 feet using 1-0 seedlings obtained from a State nursery located in Arkansas. Genetic stock was of a local-seed source. Plots were originally established in 1970 when the trees were 12 years old. Four levels of thinning, three levels of pruning, and all their combinations were included in the study design. Each combination had three replications within a randomized complete block design. Four plots were also established for each of the four thinning treatments without pruning for a total of 40 plots. Each plot had a gross size of 132 feet by 132 feet and contained an inner plot of 66 feet by 66 feet where all trees were individually numbered. Thus, the 0.1-acre measurement plot (inner plot) was surrounded by a similarly treated (including pruning) 0.3-acre buffer zone one-half chain wide. Site index (base age 25 years) was determined to be near 62 feet.

Originally, no unthinned plots were established. The need for such plots was later recognized, and at the age of 27 (in the summer of 1984) five control plots (without thinning or pruning) were established on the adjacent untreated part of the plantation. The size and arrangement of each plot was the same as that of the 40 original plots. To make growth comparable, hardwood competition was controlled on the plots by injecting Tordon® 101 R. For more detailed information, see General and others (2013).

Soil Description

The study area is located on Tippah silt loam, 1 to 3 percent slopes (USDA NRCS 2021). Tippah is classified as a fine-silty, mixed, active, thermic Aquic Paleudalf, and is situated on toeslopes of stream terraces. Tippah has a silt loam surface over a silty clay loam argillic subsoil that becomes clay by 31 inches depth. It is moderately well drained, with a seasonal high-perched water table of 18-30 inches depth in the late winter and early spring. Tippah has a slow infiltration rate, low runoff, and moderate permeability in the upper subsoil, but low permeability in the clay, lower subsoil.

The soil erodibility of the Tippah silt loam is high, with a moderate erosion hazard (off-road, off-trail) and it has zero initial and total subsidence, and low soil slippage potential. Bulk density is 1.50 g/cm^3 in the surface, and 1.48 g/cm^3 in the subsoil down to 30 inches depth and there is a medium potential for soil compaction. Restrictive soil layers are deeper than 6.6 feet from the surface. Organic matter content is low (1.25 percent) but the available water capacity of the soil is high (24 percent). Tippah silt loam is rated as somewhat favorable for aerobic soil organisms, with low organic matter, favorable bulk density, and somewhat favorable soil moisture and clay content.

Measurements

Measurements were conducted on inner plot trees that had their d.b.h. marked with a white paint stripe at age 12 (and age 27 in the unthinned portion). Careful examination resulted in the selection of trees that had level ground at 5 feet from their base to avoid measuring dips and logging activity soil displacements. After trees were selected using these criteria, the three largest-diameter and smallest-diameter trees throughout all plots were selected. All other trees were selected based on an attempt to get an even distribution of diameters. Litter and understory vegetation were cleared at the base of each tree in two general directions: north and east. A measuring stick was used to determine the height (in feet) from the existing ground-base (ground level at the base of the tree) to the white paint stripe (fig. 1), D is the difference from that height and 4.5 feet. The measuring stick was then carefully dropped on a pin and straightened by use of a level (fig. 2). Height from the ground level to the bottom of the measuring stick was made at a distance of 5 feet from the base of the tree by a ruler and defined as G. Table 1 contains summary statistics of data used in model fitting and model validation.

Figure 1—The top pictures are of tree 252, which is in plot 27, which is a 30 square feet per acre thinning plot with no pruning. The tree has a d.b.h. of 25.2 inches, and an average displacement (D) of 7.8 inches. This tree had the largest measured d.b.h. and average displacement (D). The ruler in front of the tree depicts how the ground level has increased (G) around the base of the tree, which is an average of 7.4 inches. The red line on the measuring stick is d.b.h., or 4.5 feet, while the yellow tape shows where the original white stripe d.b.h. line was placed at age 12. The bottom pictures are of tree 595, which is in plot 45, which is an unthinned and unpruned plot. The tree has a d.b.h. of 7.6 inches and had no displacement (D). The tree had an average of 0.75 inches of ground elevation (G), the lowest amount of any measured tree. The yellow tape shows where the original white stripe d.b.h. line was placed at age 27.

Figure 2—Tree 252 with a ground elevation (G) of 8.4 inches (east direction) and tree 595 with a ground elevation (G) of 0.7 inches (east direction). These pictures show how a stick was located from the base point on the tree, used to locate d.b.h., in a due east direction, a level used to ensure the stick was straight, and a ruler used to measure the amount of ground elevation (G).

Table 1—Summary statistics of data used in model fitting and model validation

Measurement		Mean	Minimum	Maximum	SD
D (inches)					
	t	3.864	1.800	7.800	1.450
	u	0.900	0.000	3.000	1.140
G (inches)					
	t	4.896	2.900	7.400	1.237
	u	2.500	0.750	5.250	1.367
D.b.h. (inches)					
	t	18.7	13.7	25.2	3.27
	u	11.7	7.1	17.8	4.14

SD = standard deviation; subscript t refers to observations from thinned treatments; subscript u refers to observations from unthinned treatments. For thinned, n = 25, and unthinned, n = 10.

ANALYSIS AND RESULTS

The relationships between D, G, and d.b.h. were analyzed using regression. Several models were examined for each dependent variable (D and G). Selection of a particular model depended both on statistical and biological criteria. For all linear models, the y-intercept was forced to zero assuming that the ground level at the study site would not sink.

A linear relationship was found between D and G (fig. 3). As ground level at the base of a tree rises, D gets larger. Linear regression was used to quantify the effects of d.b.h. on D (fig. 4) and the relationship between G and d.b.h. (fig. 5). There is a direct relationship between d.b.h. and both D and G. In all cases, linear correlations were found to be significant at least at $p < 0.0099$.

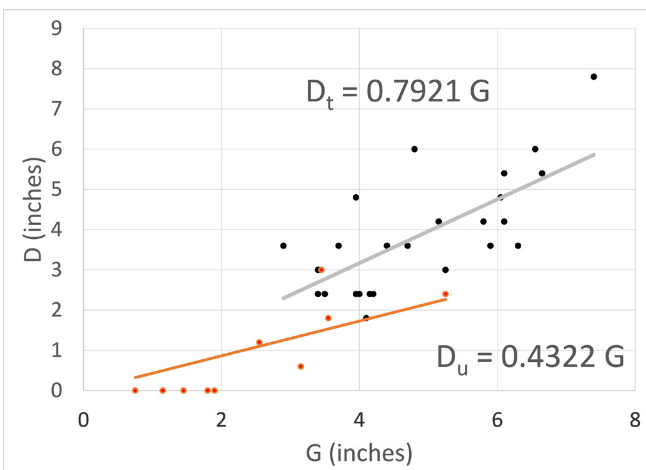

Figure 3—Relationship between D-d.b.h. displacement (inches) and G-ground-raising (inches). Subscript t refers to observations from thinned treatments and subscript u refers to observations from unthinned treatments. For thinned, n = 25, and unthinned, n = 10.

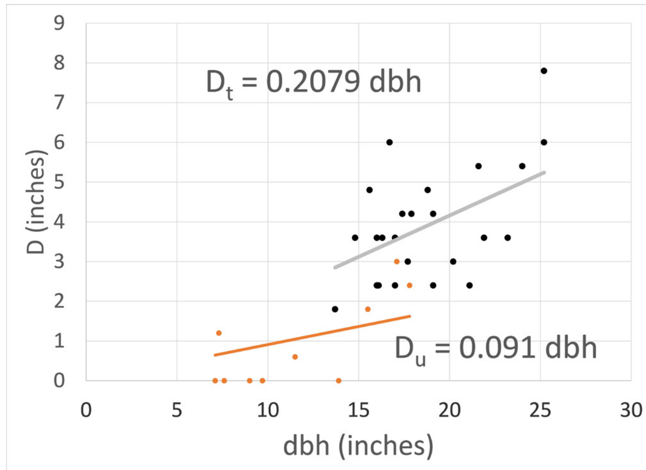

Figure 4—Relationship between D-d.b.h. displacement (inches) and d.b.h. (inches). Subscript t refers to observations from thinned treatments and subscript u refers to observations from unthinned treatments. For thinned, n = 25, and unthinned, n = 10. For thinned observations, d.b.h. is the diameter of the tree at the white stripe line originally established at age 12 while for unthinned observations, d.b.h. is the diameter of the tree at the white stripe line originally established at age 27.

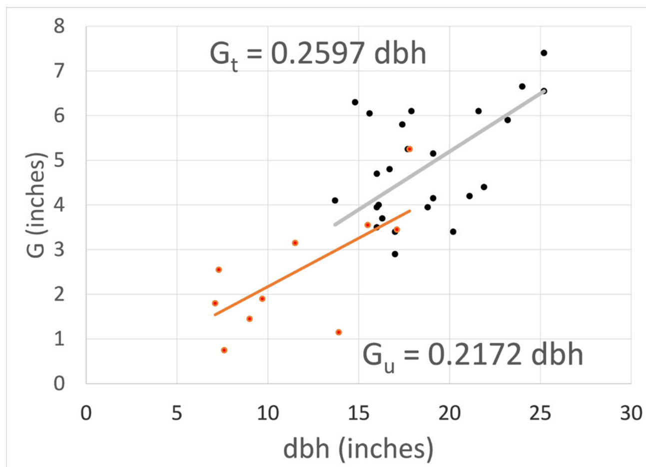

Figure 5—Relationship between G-ground-raising (inches) and d.b.h. (inches). Subscript t refers to observations from thinned treatments and subscript u refers to observations from unthinned treatments. For thinned, n = 25, and unthinned, n = 10. For thinned observations, d.b.h. is the diameter of the tree at the white stripe line originally established at age 12 while for unthinned observations, d.b.h. is the diameter of the tree at the white stripe line originally established at age 27.

DISCUSSION

It appears there is some force that causes loblolly pine trees to rise over time from ground level at the time of planting. This force is probably roots pushing the tree up (figs. 1 and 2) because of a high clay content which provides resistance to root expansion. It is known that as the above-ground component of a tree becomes larger so does its root volume (Kapeluck and Van Lear 1995, Pehl and others 1984). A lot of humus was also present in the upper 2 inches of the soil mound at the base of the study trees also resulting in the soil rising. Naturally, over a 43-year period a lot of litter accumulated.

Alternatively, this apparent rise around the tree, may in fact, slightly develop because of a corresponding decrease in soil in the distant vicinity from the base of a tree due to transpiration, where the diameter of that vicinity depends on the size, and likely species (in this case loblolly pine), of that tree. This could potentially be a third factor contributing to d.b.h. displacement. We believe this could be a potential contributor despite this site having a Tippah silt loam soil series and thus inherently low soil subsidence. The uptake of soil moisture by the tree roots and ultimate moisture transfer to the atmosphere (transpiration), plus factors such as decaying dead soil woody material, producing voids in the soil that collapse, and subsistence of microorganisms may also contribute to the soil within a vicinity of larger trees decreasing over time as a result of tree growth. Soil erosion is another potential factor that may lead to soil decrease in the distant vicinity from the base of a tree, making it appear that the tree base rose in height. This may be true given the soil properties of Tippah silt loam (soil erodibility is high, with a moderate erosion hazard) (USDA NRCS 2021). A related factor, may be some accumulation of the displaced soil around the base of a tree, causing the soil around the base of a tree to increase, and changing the point along the stem at which d.b.h. occurs through time.

Part of this soil "rise" around trees is offset by the tree sinking. Evidence for this is the fact that the increase in G is not totally accounted for by D (table 1, fig. 3). Large trees contain a lot of weight. Despite this, apparently the expansion force of roots is greater than the force of gravity pushing the tree downward.

Long-term research studies should be concerned about D. The d.b.h. of trees should be permanently marked during the establishment of studies. This will prevent errors from being made when determining both d.b.h. and volume. The decrease in d.b.h. could also, to a minor degree, result in some inconsistencies in forest inventories across rotations and theoretically total height. However, the impacts resulting from the loss in height are probably negligible, since the loss in height is probably minimal compared to the error associated with determining height for larger trees.

This may be the last publication produced by Dr. Zeide. The majority of this work was conducted when the lead author was a Research Specialist and Dr. Zeide was a professor at the University of Arkansas at Monticello.

This is a tribute to him, a person who was highly influential in the understanding of self-thinning patterns of forests and the understanding of growth equations, among other topics. He produced several highly influential papers on the self-thinning rule but his paper "Analysis of Growth Equations" (Zeide 1993) may have been his most influential work. It is currently the most cited paper in the history of Forest Science. Dr. Zeide was a very influential part of the lead author's career.

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