WOOD-BARK DENSITY OF HYBRID SWEETGUM STEMS AT AN AFFORESTED SITE IN NORTH LOUISIANA

T. Eric McConnell, Curtis L. VanderSchaaf, Robert Hane, Joshua P. Adams, and Michael Blazier

Abstract—This is the third in a series of studies to quantify yields of hybrid sweetgum (*Liquidambar formosana* x *styraciflua*) biomass at an afforested site in north Louisiana. Pooling across herbicide and varietal treatments to produce a single model system to estimate weight was determined to be statistically appropriate on the 2-year-old (1-0) seedling stock. An equation constructed from that study, where moisture content on the oven-dry basis averaged 107.5 percent (51.8 percent wet-basis), estimated the weight of standing trees. Field measurements of stem diameter occurred at 1-foot increments along the height of the stem beginning at the groundline, with height determined from pole measurements. The volume of each section was calculated using Smalian's formula and summed to provide total stem volume. Bulk density was calculated as pounds per cubic foot (pcf) green, basic density was calculated as oven-dry weight per cubic foot green volume, and specific gravity was the ratio of basic density to the density of water. Bulk density, basic density, and specific gravity were all calculated outside bark. Mean values for bulk density, basic density and specific gravity were 61.6 pcf, 29.7 pcf, and 0.48, respectively. The results suggested the hybrid sweetgum density properties exceeded published values for native sweetgum (*L. styraciflua*), while moisture content was lower. Seasonal influences could have affected moisture content and bulk density. However, basic density and specific gravity findings suggest potential exists to benefit a number of both traditional (e.g., logging, pulp, and paper) and newer (pellet, biofuel) industries, as wood properties correlate strongly with product output in these industries.

INTRODUCTION

Sweetgum (*Liquidambar styraciflua*) is the most populous hardwood species growing on southern pine sites in the South (Koch 1985). While sweetgum lumber is visually appealing, maintaining lumber quality through the drying process is very difficult. The value of sweetgum to the hardwood industry is mostly in lower-valued industrial products, such as railroad ties, pallets, and mats.

The chemical characteristics and timber value of sweetgum, however, could make wood fuel conversion more cost effective. The species has long been a resource suited to pulping and is increasingly being pelletized where that market exists in the South. Partially hydrolyzing sweetgum to harvest wood sugars for biofuels was concluded as more favorable than other high-volume hardwood species, such as red oaks (*Quercus* spp.) and yellow-poplar (*Liriodendron tulipifera*) (McConnell and Shi 2011). The high percentage of 5-carbon sugars and hemicellulose fraction make sweetgum a more efficient choice for wood sugar harvesting. Recent positions of the United States regarding global relations and trade continue to emphasize the need for energy independence. Thus, efforts should be continued to convert lignocellulosic materials, including wood, to solid or liquid fuel. Regardless, global timber consumption is directly related to population (FAO 2018). Meeting the needs of 9 billion people by 2050—whether wood, fiber, or fuel—will require novel forest management strategies.

A relatively new forestry practice becoming more commonplace is short rotation woody crop (SRWC) forestry, where the goal is to cultivate a crop of trees as rapidly as possible using techniques needed to improve growth rates (Kaczmarek and others 2012). Genetic improvements in the last couple of decades within the *Liquidambar* genus and others through hybridization within genus, genetic manipulation, and clonal replication created faster-growing individuals capable of rapidly responding to fertilizer or release treatments to capitalize on monetary inputs to the stand (Scott and others 2004b). Sweetgum, along with its associated hybrids, is being investigated as a SRWC resource, but many questions regarding SRWC need

Author information: T. Eric McConnell, Assistant Professor, Louisiana Tech University, Ruston, LA 71272; Curtis L. VanderSchaaf, Assistant Professor, Louisiana Tech University, Ruston, LA 71272; Robert Hane, Graduate Student, Louisiana Tech University, Ruston, LA 71272; Joshua P. Adams, Assistant Professor, Louisiana Tech University, Ruston, LA 71272; and Michael Blazier, Professor, Louisiana State University AgCenter, Homer, LA 71040

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answering. Some, such as fertilization requirements, must be considered prior to establishing a SRWC plantation (Kline and Coleman 2010), while others, such as estimations of biomass and volume, are also needed to periodically assess stand productivity.

Both biomass and volume involve the raw material from the perspective of the processor, that is, the purchaser. Wood density and specific gravity correlate well with many product properties (Shmulsky and Jones 2011). Thus, an understanding of wood-bark stem density at a young age can help managers across the value chain assess the viability of the species in a SRWC setting.

A study was established in north Louisiana to examine the interactive effects of herbaceous competition control (two treatments) and genotype (five varieties) on growth and yield of hybrid sweetgum (*Liquidambar formosana* x *styraciflua*). The objective of this component of the study was to determine wood-bark stem density in response to these treatments.

METHODS

The study was located at Louisiana Tech University, South Campus (32° 30' 49.84" N. 92° 39' 11.59" W) in Ruston, LA. The study site was largely on an Angie fine sandy loam soil (Aquic paleudult), with a small portion on a Sacul very fine sandy loam (Aquic hapludult) (USDA NRCS 2019). The site had been used for grazing and hay production since 1990. During this time, horse manure was spread over the field occasionally as fertilizer. Prior to 1990, the site was the interior of a racetrack dating back to the late 1970s, during which time Christmas trees were periodically grown on the site.

No fertilizer treatment was applied prior to planting because of the history of manure fertilization of the site (Scott and others 2004a). In preparation for planting, the site was subsoiled (ripped) to a 24-inch depth in late summer. One week before planting, 3 quarts per acre of glyphosate was applied (Accord XRTII® [Dow; Indianapolis, IN]) via ATV sprayer to remove any herbaceous vegetation present. Prior to planting, containerized seedlings were left outside under a covered awning and watered daily to prevent soil from drying out. Seedlings were planted by hand in late October 2015; no significant slope was present.

Five hybrid sweetgum varieties were tested (AGHS1, AGHS2, AGHS3, AGHS4, AGHS8). The study was laid out in a split-plot design, with herbicide being the main plot and genotype as the sub-plot. Five replications were installed. Each row of the study was considered one plot, receiving a random herbicide treatment. The rows were divided into sub-plots of eight seedlings of each genotype; the internal six seedlings of each sub-plot were considered the test sub-plot, while the seedling at either end of the sub-plot was considered a border tree and removed from analysis. A total of 640 seedlings were planted. The seedlings were planted 5 feet apart along the row, and rows were 10 feet apart.

The herbicide tested was sulfometuron methyl (Oust XP®). Oust XP® was applied in a 36-inch wide band using a boom sprayer attached to a tractor at 2 ounces per acre directly over the seedlings. The rate of 2 ounces per acre was selected in accordance with recommendations for sweetgum based on prior studies (Kushla and Self 2013). Four herbicide timing treatments were conducted: a no-herbicide control, mid-winter, late winter, and early spring. In the component of the study reported here, trees within two of the herbicide treatments were studied, the control and the late winter timing. For the late-winter treatment Oust XP® was applied on February 17, 2016. This treatment coincided with the chemical company recommendations for Oust XP® to prevent seedling damage, while still controlling competing vegetation into the growing season.

Measurements on 80 standing trees were conducted in November 2017. To determine if herbicide application and/or variety caused a change in growth characteristics of seedlings after 2 years, randomly chosen seedlings from each block were measured. Height was measured in 1-foot increments using a height pole from the ground level up to the highest living bud present on the seedling. Diameter was measured in millimeters using calipers at each increment on the lower and upper ends of the stem section beginning at the groundline. Groundline diameter (GLD) was measured at ground level unless roots were exposed above the ground, where instead GLD was taken at the root collar. Stem volume—both wood and bark—was calculated using Smalian's formula for each section and summed to obtain total stem volume. GLD, total height, green volume, green weight, and oven-dry weight are provided in table 1.

Statistical analysis (e.g., dummy variables) of stem weight concluded separate biomass equations were not necessary by herbicide, variety, or herbicide and variety interaction. The data were therefore pooled across varietal and herbicide treatments to produce a single model system:

$$\widehat{WT} = 146.6221 + 0.001874 D_G^2 H \qquad (1)$$

where

D_G^2 is the square of GLD and H is total tree height (both measured in metric units; VanderSchaaf and others 2018).

Table 1—Descriptive statistics for groundline diameter, total height, green volume, green weight, and oven-dry weight of hybrid sweetgum grown on an afforested site in north Louisiana (*n* = 80 trees)

Statistic	Groundline diameter	Total height	Green volume	Green weight	Oven-dry weight
	inches	*feet*	*cubic feet*	*pounds*	*pounds*
Mean	1.35	6.83	0.025	1.45	0.70
Standard deviation	0.32	1.07	0.013	0.70	0.34
Maximum	2.17	9.25	0.075	3.87	1.87
Minimum	0.74	4.70	0.006	0.59	0.28
Median	1.32	6.87	0.023	1.27	0.62

Green volume and green weight at 107.5 percent moisture content.

Destructive samples of 80 standing trees taken in March 2018 were used to obtain green stem weights. Samples were then dried in a laboratory oven at 140 °F until a constant weight was obtained for calculating moisture content on an oven-dry basis. All measurements were converted to English units (inches and feet) for this work.

Bulk density was measured as green weight per unit green volume of wood-bark (pounds per cubic foot, pcf). This bulk density calculation differs from the more common expression of bulk density as green weight of wood-bark per cubic foot of wood, but it is similar to Patterson and Wiant (1993) as well as Lenhart and others (1995) interpretations. Basic density was calculated as oven-dry weight per cubic foot green volume of wood-bark. Specific gravity was the ratio of basic density to the density of water. Because varietal and herbicide treatment effects were not significantly different for the earlier biomass study (Equation 1, VanderSchaaf and others In press), the results here were likewise pooled across herbicide and variety.

We used one-sample *t*-tests (assuming equal variance, Equation 2) to compare our specific gravity results with the means reported for natural sweetgum from Clark and others (1985), Manwiller (1979), and the Forest Products Laboratory (2010):

$$t_{stat} = \frac{\bar{x} - \mu}{s / \sqrt{n}} \qquad (2)$$

Where t_{stat} was the test statistic calculated from a t distribution, $\bar{x}$ was our sample's mean specific gravity, μ was the published mean being compared, and $s / \sqrt{n}$ was our sample's standard error.

The test statistic was compared to a critical value, $t_{critical}$, at $\alpha = 0.05$ and $n - 1 = 79$ degrees of freedom. The effect of moisture content was eliminated from specific gravity, thus only that measure's results were tested for significant differences.

RESULTS AND DISCUSSION

Descriptive statistics for bulk density, basic density, and specific gravity are provided in table 2. Bulk density averaged 61.6 pcf at an average moisture content of 107.5 percent, dry basis (51.8 percent wet basis). Bulk density ranged from 45.5 pcf to 97.2 pcf, with a 95 percent confidence interval of 59.4 pcf to 63.9 pcf. Basic density averaged 29.7 pcf, with a 95 percent confidence interval of 28.6 pcf to 30.7 pcf. Specific gravity ranged from 0.35 to 0.75, with an average of 0.48. The interval at 95 percent confidence was 0.46 to 0.49.

Little data on direct biomass measurements for similarly sized trees and site conditions are available, but other regional works have highlighted stem property estimates of naturally grown, native sweetgum wood-bark. Clark and others (1985) found saplings 1.0 to 4.9 inches in diameter at breast height (d.b.h.) in the Gulf and Atlantic Coastal Plains averaged a specific gravity of 0.46. Moisture content averaged 106 percent, while mean bulk density was 56.0 pcf for wood and bark. Manwiller (1979) determined wood-bark stem bulk density of 6-inch native sweetgums growing on pine sites averaged 59.2 pcf, with a specific gravity of 0.44. Wood-bark bulk density averaged 61.6 pcf across a d.b.h. range of 6 to 30 inches for naturally grown sweetgum in east Texas and west Louisiana (Lenhart and others 1995); the smallest d.b.h. class in that study, 6 to 8 inches, averaged 59.4 pcf bulk density. The Wood Handbook (Forest Products Laboratory 2010) reported an average wood specific gravity of 0.46 across the species home range. Typical on-the-stump moisture contents were presented as 137 percent for sapwood and 79 percent for heartwood.

Specific gravity results from the *t*-test between the hybrid sweetgum and those from Clark and others (1985) suggested the results obtained here were significantly higher ($t_{stat} = 2.302 > t_{critical} = 1.645$). The hybrid sweetgum also produced results significantly

Table 2. Descriptive statistics for bulk density, basic density, and specific gravity of hybrid sweetgum grown on an afforested site in north Louisiana (n = 80 trees)

Statistic	Bulk density	Basic density	Specific gravity
	pounds per cubic foot at 107.5 percent moisture content	*oven-dry pounds per green cubic foot*	
Mean	61.6	29.7	0.48
Standard deviation	10.2	4.86	0.08
Standard error	1.14	0.54	0.01
Margin of error	2.24	1.06	0.02
95% Confidence interval lower bound	59.4	28.6	0.46
95% Confidence Interval upper bound	63.9	30.7	0.49
Median	58.7	28.3	0.50
Maximum	97.2	46.8	0.75
Minimum	45.5	21.9	0.35
Range	51.6	24.9	0.40

greater than Manwiller (1979) (t_{stat} = 4.102 > $t_{critical}$ = 1.645). Mean differences were less between the hybrid sweetgum and the published value in the Wood Handbook (Forest Products Laboratory 2010), but were still significantly different (t_{stat} = 1.740 > $t_{critical}$ = 1.645).

The results obtained here, while limited in scope, are encouraging. Higher specific gravity is indicative of higher fiber content and less air void space per unit volume. If this is indeed the case for the hybrid over naturally grown sweetgum, it can potentially lead to greater processing yields. A specific gravity increase of 0.02, for example, extrapolates to approximately 1.25 oven-dry pounds of wood-bark per green cubic foot that would be available for conversion to fiber products or fuel. Moreover, a lower moisture content indicates more wood can be hauled at an equivalent payload. Assuming loaded trucks average 27 tons, a 2 percent decrease in moisture content provides loggers 1,080 additional pounds of available payload. These conditions equate to hauling four more 35-foot-long pulpwood sticks measuring 6 and 3 inches outside the bark at each end, where each stick possesses the average bulk density from table 1. At current (spring 2019) north Louisiana delivered pulpwood prices of $34.80/ton (TimberMart-South 2019), this equates to $18.80 more revenue per truck (1,080 divided by 2,000 pounds per ton multiplied by $34.80). Were 15 truckloads delivered per day, this would exceed $280 per day of additional revenue.

Moisture content directly affects bulk density measurements, as bulk density is weight per cubic foot at a specified moisture content. Koch (1985) recorded multiple studies across the South that reached varying conclusions regarding moisture content seasonality of southern pine site hardwoods. Some reported no seasonal differences, while others reported complex, multi-variable interactions. Doruska and Patterson (2006) found seasonal differences in loblolly pine (*Pinus taeda* L.) pulpwood logs in southeast Arkansas. Newbold and others (2001) concluded water comprised a greater fraction of green weight in young plantations up to 20 years of age, but moisture content of planted loblolly pine overall was not seasonally influenced in north Louisiana. Where tree/log moisture content seasonality has been found, winter moisture contents were generally lower than at least one other season.

Moisture content for this project was determined in a companion study in March 2018. If a seasonality effect were present, it is possible that the moisture content, and thus bulk density, found here may be lower than the annual average. If this is the case, logging productivity could be affected seasonally since water would represent a higher percentage of the delivered load weight when seasonal moisture contents are higher.

From a mill's perspective, whether paper or liquid/solid fuel, basic density and specific gravity are the wood properties better correlated with fiber input and product output, and each property is moisture invariant. This is because both basic density and specific gravity are calculated using wood (or wood-bark) oven-dry weight and green volume. Both are assumed to be constant, as the wood weight does not change at zero percent moisture content. Likewise, wood does not change volume in the green condition above fiber saturation point (approximately 30 percent moisture content across species). The moisture content of the living tree is thus negated. Using native sweetgum as a guide (e.g., Clark and others 1985), both basic density and specific gravity should increase with tree age to financial maturity.

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