CALORIC CONTENT ESTIMATION AND DISTRIBUTION IN SEVEN BOTTOMLAND HARDWOOD TREE SPECIES GROWING IN NATURAL STANDS IN THE SOUTH

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Abstract.--Caloric values (calories per gram of dry weight) were determined by bomb calorimetry for bole wood and bark, branch wood and bark, and foliage for seven bottomland hardwood species in natural stands. Stem wood and bark caloric values are based on 5- to 10-cm-thick disks removed at butt, diameter at breast height (dbh), quarter heights and heights to 10- and 5-cm diameter outside bark (dob) points on tree boles.

Species ranked according to their mean bole wood caloric value from highest to lowest are black gum (*Nyssa sylvatica* Marsh), red maple (*Acer rubrum* L.), water tupelo (*Nyssa aquatica* L.), green ash (*Fraxinus pennsylvanica* Marsh), hickory (*Carya* spp.), water oak (*Quercus nigra* L.), and sweetgum (*Liquidambar styraciflua* L.). Bole wood caloric values on a dry weight basis ranged from 4703 cal/g for black gum to 4552 cal/g for sweetgum.

A Chi-square test was performed to evaluate a single disk sampling method to estimate a weighted caloric value of tree tissue. The Chi-square test compared the species mean caloric value for each position to a calculated weighted caloric value for each species. Weighted values were computed by multiplying the stem position caloric value by the stem volume the sample position represented, summed over the entire stem, and divided by the total stem volume. Using the Chi-square test, the one-half height disk estimated the weighted mean caloric value for all species means (within five percent) 99 percent of the time.

Energy content and biomass production of southern hardwoods are useful measures of resource values and productivity. Because intraspecies caloric values are relatively uniform and interspecies caloric value variation is small, the developed energy sampling and analysis techniques may prove useful for other species and other regions.

Keywords: Caloric values, energy content, southern hardwoods, sampling scheme

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INTRODUCTION

Woody biomass is established as an economically feasible energy source. The wood products and pulp and paper industries have taken the lead in this field in an effort to become energy self-sufficient. Resource availability and reliability are the major constraints preventing the large-scale use of woody biomass for energy production for nonforest-based industries. Use of wood for electricity and domestic heating has also been increasing. A recent Worldwatch reported that in 1980 twenty percent of the homes in northern New England were entirely heated by wood (Smith, 1981).

Caloric values for numerous hardwood tree species of the central and southeastern United States have been determined, using a variety of sampling schemes (Hough, 1969; Neenan and Steinbeck, 1979; and Musselman and Hocker, 1981). No reports have been found in which someone has developed a within-tree sampling scheme to represent adequately the energy values of different morphological components of a tree. Quantification of the energy content of the residual trees, tree crowns and branches remaining after a harvest is needed, considering the increasing intensive utilization standards.

In this study an intensive tree sampling scheme was undertaken to determine if caloric value trends existed in stem and branch wood or bark components. The developed subsampling procedure will be used to estimate the energy content in the dominant and subordinate vegetation components of major hardwood species and site types on the Coastal Plain. The additional information should provide better estimates of the potential energy yields of different hardwood site types.

FIELD METHODS

Three site types on the Atlantic and Gulf Coastal Plains were chosen for study and included: (1) Bottomland--floodplain of a major drainage system in which drainage is fairly rapid and the soils are loam to silt loam; (2) Swamp--broad interstream areas characterized by very poor drainage, with silt loam to clay soil that contains large amounts of raw organic material; (3) Wet Flat--broad interstream areas in which drainage is intermediate between bottomlands and swamps and the soils are nonalluvial and contain some organic matter accumulation. Based on USDA SEFES Survey Reports, the three site types represent a majority of the natural hardwood forests of the Atlantic and Gulf Coastal Plain.

Each site type was represented by two replications of 10- (6-15), 20- (16-25), 40- (36-45), and 60- (56-65) year-old stands. The only exception was the 40-year-old bottomland type which consisted of three study sites. Stands were even-aged and age was determined by ring counts or known stand history.

A 0.04-hectare (0.1-acre) sample plot was randomly located in each selected study site. All saplings 2.5 to 12.4 cm dbh, pulpwood 12.5 to 27.9 cm dbh, sawtimber greater than 28.0 cm dbh were cut, measured and sampled for biomass and energy content. Stem length for felled trees was measured to breast height, quarter points, 10 and 5 cm dob, and total height. Cross-sectional disks approximately 3.8 cm thick were removed at the butt, breast height, quarter, half and three-quarter heights, and 10 and 5 cm dob points. The stem sections were weighed in the field to the nearest 0.1 kg, using a 136-kg capacity scale. Branches were removed from the stem prior to weighing and classified according

to size: (1) extra large branches > 10.0 cm dob; (2) large branches > 5.0 and ≤ 10.0 cm dob; (3) medium branches > 1.2 and ≤ 5.0 cm dob; (4) small branches ≤ 1.2 cm dob. A sample disk for each branch size category was located at mid-length and subsampled for energy content determination. Foliage was subsampled from three to four branches up the stem and composited. Branches were then weighed with and without foliage. Additional trees of the major species were randomly sampled outside the circular 0.04-ha plot when necessary to provide a minimum of three trees per 2.5-cm diameter class for future studies.

Seven hardwood species were chosen based on highest species frequency in the three site types. Six randomly selected trees from the total number of harvested trees in all plots for each species were included in the analysis. The species included sweetgum (*Liquidambar styraciflua* L.); red maple (*Acer rubrum* L.); green ash (*Fraxinus pennsylvanica* Marsh) from a 40-year-old bottomland site in Marion County, South Carolina; black gum (*Nyssa sylvatica* Marsh) from a 60-year-old swamp in George County, Mississippi; water tupelo (*Nyssa aquatica* L.) from a 40-year-old swamp in Hertford County, North Carolina; hickory (*Carya* spp.) from a 40-year-old bottomland in Dallas County, Alabama; and water oak (*Quercus nigra* L.) from a 40-year-old wet flat in Taylor County, Florida.

LABORATORY PROCEDURES

Green weights of individual stem disks were recorded with and without bark to the nearest 0.1 gram. A 60° wedge of wood and a random sample of bark were then removed and dried at 70° C to a constant weight for caloric content analysis. Branch samples were treated in a similar manner except branches less than 1.2 cm were not debarked. Foliage samples were weighed green and dried at 70° C to a constant weight. Wood, bark and foliage samples were then ground in a Wiley mill to pass an 0.85-mm screen and stored in air-tight plastic vials. Energy values were determined, using a Parr 1241 adiabatic oxygen bomb calorimeter (Anonymous, 1975). The reported caloric values in this paper were averaged over all positions of similar plant tissue for each tree. Mean values were based on the six sample trees per species.

A weighted segmental average caloric value concentration for each tree's stem wood and stem bark tissue was calculated (Figure 1). Segmental caloric value contents were computed by multiplying the weighted segmental average caloric value concentration times the segmental volume. A weighted mean caloric value for individual tree's bole wood and bole bark component was calculated by summing the calculated segmental caloric value contents of a tree and dividing by the sum of the stems' segmental volumes. Branch wood and bark weighted mean caloric values were calculated in a similar manner except the weighting factor was weight, not volume.

Figure 1. Calculation of a weighted segmental average caloric value concentration

$$\frac{((dib_{d\ell})^2 \times c.p.g._{d\ell}) + ((dib_{du})^2 \times c.p.g._{du})}{(dib_{d\ell})^2 + (dib_{du})^2}$$

$dib_{d\ell}$ = diameter inside bark of lower disk; dib_{du} = diameter inside bark of upper disk; $c.p.g_{d\ell}$ = caloric value of lower disk; $c.p.g_{du}$ = caloric value of upper disk.

Statistical analyses were performed to examine within-tree caloric content variation. A Chi-square test and a stepwise regression technique were performed to evaluate a single disk sampling method. The accuracy of each disk's caloric value was tested against the calculated weighted mean caloric value for each tissue. The analysis included 42 trees of seven hardwood species to determine if a common disk over all species would adequately represent the weighted mean caloric value of each tissue type.

RESULTS AND DISCUSSION

The stepwise regression technique was inadequate in selecting one disk that estimated the component's calculated weighted mean within five percent for all species, 99 percent of the time. A Chi-square test was considered because the t-test was shown to be less desirable for tests of accuracy (Freese, 1960). According to Freese (1960), the t-test is not suitable for tests of accuracy because it uses one form of accuracy (precision) to test for the other form of accuracy (freedom from bias).

Using the Chi-square test, the half-height disk provided the best accuracy in comparison to the species weighted mean bole wood caloric value. The species mean caloric values at the half height disk estimated the species weighted mean caloric values within five percent 99 percent of the time. All other bole wood positions met the abovementioned accuracy standards. No significant differences in the mean caloric values among stem wood disks within a species were observed except for hickory and water tupelo (Table 1). These results show that stem wood caloric values are not significantly influenced by stem position for black gum, green ash, red maple, sweetgum and water oak. Although several water tupelo stem wood disks were significantly different ($p = .05$) from other disks, no detectable trend was apparent. However, in hickory the stem wood caloric values consistently increased up the stem. Strong (1980) noted a similar increase in caloric value up the stem wood for *Populus* clones. The one-quarter-height disk was the most accurate disk in approximating a species weighted mean bole bark caloric value although all caloric values for bole bark were within five percent of the weighted mean 99 percent of the time. To facilitate comparison between bole wood and bole bark caloric values, the one-half-height disk will be utilized in future studies.

Table 1.--Species mean bole wood caloric value variation among sampling positions

Disk Position	Black Gum	Green Ash	Hickory	Red Maple	Sweetgum	Water Oak	Tupelo
	cal./g						
butt	4621 a	4635 a	4526 b	4716 a	4586 a	4610 a	4612 c
dbh	4629 a	4639 a	4578 b	4690 a	4582 a	4609 a	4637 abc
¼ ht.	4694 a	4659 a	4604 ab	4616 a	4384 a	4608 a	4622 bc
½ ht.	4680 a	4621 a	4621 ab	4624 a	4598 a	4583 a	4690 a
3/4 ht.	4685 a	4649 a	4629 ab	4880 a	4607 a	4599 a	4648 abc
10 cm dob	4890 a	4666 a	4627 ab	4622 a	4556 a	4599 a	4679 ab
5 cm dob	4753 a	4620 a	4729 a	4659 a	4546 a	4603 a	4628 bc

1/ Tree position entries within a species with different letters are significantly different at the .05 level.

The medium-sized branch section (branches > 1.2 and ≤ 5.0 cm dob) was selected to determine the caloric value of branch tissue. Initially the medium-sized branches were separated into wood and bark components. However, after preliminary analysis showed no significant difference ($p < .05$) between species mean caloric values of branch wood and branch wood plus bark, a composite wood and bark sample was used.

There were no significant differences in foliage caloric values among species (Table 2). The foliage caloric values for red maple, water oak, and green ash were 1, 6 and 8 percent lower, respectively, while sweetgum was 2 percent higher than the values for similar species reported by Neenan and Steinbeck (1979). Variation in caloric value between species has been reported by Golley (1961) and Malone (1968). The variation in caloric values between species found in our study is similar in magnitude to that reported by others (Neenan and Steinbeck, 1979; Musselman and Hocker, 1981). Excluding green ash and hickory, foliage caloric values were higher than the other tree tissue components but were only significantly higher in red maple, sweetgum, water oak and water tupelo ($p < .05$) (Table 3).

Table 2.--Variation in caloric value variation of tree tissue among seven Coastal Plain hardwood species

Species	Tree Components				
	Bole Wood	Branch Wood	Bole Bark	Branch Bark	Foliage
	cal/g				
Black Gum	4703 a	4758 a	4665 ab	4809 a	4995 a
Green Ash	4642 abc	4694 b	4575 b	4681 bc	4679 a
Hickory	4616 bcd	4512 d	4188 c	4203 e	4576 a
Red Maple	4687 ab	4636 bc	4250 c	4445 d	4869 a
Sweetgum	4552 d	4577 cd	4197 c	4390 d	4722 a
Water Oak	4605 cd	4576 cd	4663 ab	4621 c	4767 a
Water Tupelo	4645 abc	4690 b	4764 a	4740 ab	4900 a

1/ Species within each tree tissue component with different letters are significantly different at the 0.05 level.

Bole wood caloric values for the seven species ranged from 4552 to 4703 cal/g for sweetgum and black gum, respectively. Between-species caloric values were found to be significantly different (Table 2). The bole wood caloric values differed by no more than 3.6 percent from values of four similar species used by Neenan and Steinbeck (1979). Black gum had the highest branch wood value, while hickory had the lowest branch wood value but differed by only 5.2 percent. Significant differences in the branch wood values among the seven species were also detected (Table 2). The mean caloric values of bole wood for the seven species were not significantly different ($p = .05$) from their branch wood values (Table 3). Musselman and Hocker (1981) also found no significant difference ($p < .01$) in the caloric values between bole wood and branch wood among seven hardwood species.

Table 3.--Comparison of tree component caloric value variation within species for seven Coastal Plain hardwood species

Tree Component	Species						
	Black Gum	Green Ash	Hickory	Red Maple	Sweetgum	Water Oak	Water Tupelo
	cal/g						
Foliage	4995 a	4679 a	4576 a	4869 a	4727 a	4767 a	4900 a
Bole Wood	4703 b	4642 a	4616 a	4687 b	4552 b	4605 bc	4645 c
Branch Wood	4758 ab	4694 a	4512 a	4636 b	4577 b	4576 c	4690 bc
Bole Bark	4665 b	4575 a	4188 b	4250 d	4197 d	4663 b	4764 b
Branch Bark	4809 ab	4681 a	4203 b	4446 c	4390 c	4621 bc	4740 bc

1/ Tree components of a species with different letters are significantly different at the 0.05 level.

Within-tree caloric values of bole bark and branch bark varied much more than bole wood and branch wood. Differences of 12.1 and 12.6 percent were observed between the highest and lowest caloric values of the seven hardwood species in bole bark and branch bark, respectively. Neenan and Steinbeck (1979) reported a similar variation in bole bark. The larger variation in the bark versus wood component is possibly related to the larger variation in bark types and bark tissue constituents compared to wood tissue. There were significant differences within tree for bole and branch bark (Table 2).

CONCLUSIONS

Calorimetric methods allow productivity comparisons to be made among species, ecosystems, or other biological levels. Golley (1961, 1969) and Bliss (1962) demonstrated that environmental conditions can influence the caloric values of plant tissue but emphasized these differences are not significantly different within a climatic zone. Comparison of red maple bole wood caloric values presented in this paper with the caloric values presented by Hocker (1981) and Neenan and Steinbeck (1979) reveals a 3.4 percent caloric value variation in red maple from New Hampshire, Georgia and South Carolina. Excluding foliage, tissue caloric values within species were significantly different; however, the percent difference between the lowest and highest mean values was relatively small.

Based on the 42 trees sampled and the described sampling procedure, we feel that the species mean caloric value at any bole or branch sample position adequately estimates the weighted mean of the species. Selection of a position(s) in which other parameters such as biomass or nutrients can concurrently be estimated accurately should be considered so maximum information can be obtained at a minimal cost. These results indicate a small caloric value variation within a given vegetative tissue. A similar sampling scheme as the one presented in this paper would probably be satisfactory for future energy productivity studies in other hardwood stands.

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