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EFFECTIVE ENERGY OUTPUT PER CORD OF AIR-DRIED WOOD IN FIVE NATIVE, AMERICAN HARDWOODS FROM A TYPICAL TENNESSEE WOODPILE

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ABSTRACT--Calories per gram, moisture content, and density were determined for five species of equally seasoned hardwood. These data were used to calculate the effective British Thermal Unit (BTU) per cord in *Quercus alba* (white oak), *Quercus velutina* (black oak), *Liriodendron tulipifera* (yellow poplar), *Carya ovata* (shagbark hickory), and *Cornus florida* (flowering dogwood). These species were compared at typical moisture contents on an available-heat-per-volume basis to determine the best woodfuel value for the homeowner as well as for industry. While calories per gram were similar across species, the differing moisture contents and densities produced significant differences in the amount of available heat per volume of wood.

Since the energy shortages of the 1970s, there has been an increased interest and reliance on wood as a source of fuel for home heating and as a renewable energy resource for industry (Curtis, 1980; White and Wilson, 1981). With the renewed awareness on energy, conservation, and renewable resources due to the Persian Gulf War, a corresponding rise in fuelwood consumption may occur again. There is considerable interest by industry in biomass energy production as a renewable energy source with experimentation on several different species (Neenan and Steinbeck, 1979; Wang et al., 1982). However, the average woodlot owner who heats his home with woodfuel is more likely to have the typical variety of trees available. This study is designed to help the woodlot owner select the species for harvest that will provide the most heat for the amount of time and effort invested. Also, the homeowner that heats the domicile with purchased woodfuel may benefit from the results of this study by selecting for purchase those species that provide the most heat per dollar. Industrial users of woodfuel may benefit also from this information as the typical wood burned in industrial applications is in the air-dried state as opposed to the oven-dried state. Most studies involving heat content of wood are conducted on oven-dried samples. However, different species contain various amounts of moisture in the air-dried state resulting in a reduced effective energy output per unit of wood (Ince, 1977). Since most users of woodfuel do not oven-dry their wood before burning it, this should have a more practical application than one involving oven-dried wood. Since one disadvantage to wood as a fuel is its bulkiness, a wood with more heat per cord is of greater value as each unit of heat takes up less storage space, requires less hauling and lifting, and, if purchased by the cord, costs less per unit of heat. Therefore, higher effective BTU (British Thermal Unit) per cord corresponds to a savings of space, time, effort, and money.

Five common fuelwood species of a typical southern hardwood forest were examined in the present study: *Quercus alba* (white oak), *Quercus velutina* (black oak), *Liriodendron tulipifera* (yellow poplar), *Carya ovata* (shagbark hickory), *Cornus florida* (flowering dogwood). The purpose of the present study was to determine if these five species differ in effective BTU per cord.

MATERIALS AND METHODS

Five young trees of each species, except black oak for which there were four, were collected. These 24 trees were taken from a 1,380-m^2 area of second-growth forest last known to be logged circa 1936; all were 10 to 30 years old. This should be representative of the species as a whole (Neenan and Steinbeck, 1979). The 30.5- by 45.7-m harvest site of rolling, clay ridges is located in southern Cheatham County, Tennessee. All trees were collected on the same day in June 1990 and left on site, raised off the ground, and loosely stacked. All trees were harvested at ground level. Sample blocks were taken from a 0.3-m section approximately 0.6 to 0.9 m above the harvest cut. Experimentation was begun on 28 March 1991. Disks approximately 2.5 cm thick were cut from the 0.3-m sections. Four disks were taken from each 0.3-m block. The bark was separated from the wood and ignored for this study. Each sample was weighed and marked, and circumference and height of each block was measured to determine volume and density. The following formulae were used: radius = circumference/2π; volume = $\pi(\text{radius})^2$ height. Density is weight per volume or, in this case, grams per cubic centimeter. Therefore, density in grams per cubic centimeter = grams/$[\pi(C/2\pi)^2h]$. All samples were dried in an oven at 105°C until constant weight was obtained. Air-dry weights and oven-dry weights were used to determine moisture content. Moisture content was determined for each individual with the formula MC = grams water/(grams water + grams wood) or MC = (air-dry weight - oven-dry weight)/air-dry weight (Ince, 1977).

A wood rasp was used reduce each sample to pass a 20-mesh sieve. The ground material was compressed into nominal 1-g pellets and fired in a Parr Plain Jacket oxygen bomb calorimeter. The energy coefficient of the calorimeter was determined with a standardized benzoic acid tablet. For each wood sample, the pellet was placed in the flash pan, a 10-cm fuse wire was attached to the electrodes and brought into contact with the sample, and 1 ml of distilled water was placed in the bottom of the bomb. The bomb was then pressurized to 20 to 25 atmospheres of oxygen and placed in the calorimeter bucket in 2,000 g of distilled water. The cover was put in place, and the stirring motor started. The temperature was allowed to equilibrate for 5 min, recorded, and corrected using the chart provided with the thermometer. The bomb was then fired. The subsequent temperature rise was then observed to the point when the temperature remained stable or changed at a constant rate for 5 min (instructions from Parr Instrument Company). The appropriate temperature was then recorded and corrected as previously mentioned. The stirring motor was stopped, and the cover removed. The bomb was lifted from the bucket, the pressure was slowly released from the bomb, and the cover was removed. The remaining fuse wire was collected and measured, and washings were taken from all interior surfaces of the bomb. The length of the fuse wire remaining was subtracted from the amount placed in the bomb with the sample. The washings were brought to a standard volume of 30 ml, and one drop of methyl orange-saturated solution was added. Sodium carbonate solution (0.0725 N) was titrated to a point where the color changed from red to orange. The milliliters of sodium carbonate solution used was recorded and used to correct heat output.

The energy coefficient (W) obtained by firing a standardized benzoic acid tablet was determined with the formula W = [6318(weight of benzoic acid tablet in grams) + correction factor]/(final temperature - initial temperature). The correction factor is the length of fuse wire burned in centimeters multiplied by 2.3 plus the number of milliliters of sodium carbonate used. This number (W) is then used to calculate results in each subsequent test. The final and initial temperatures must be corrected as previously described. The calories per gram for each sample was determined by the following formula: calories per gram = [(final temperature - initial temperature)(W) - correction factor]/sample weight in grams.

Three experimental parameters were gathered on the wood samples. These were moisture content, density of the oven-dried wood, and calories per gram. Using these data, and several mathematical calculations and formulae, the final comparison of effective BTU per cord can be achieved. Density, calories per gram, moisture content, total BTU per cord, and effective BTU per cord were tested for significant differences ($P \leq 0.05$) among species with oneway analysis of variance tests.

RESULTS AND DISCUSSION

Data were excluded for firings that resulted in incomplete combustion. Therefore, the total number of fired samples for which data are available is 69 (Table 1). Although an effort was made to fire an equal number of samples from each tree, not all individual trees are equally represented. However, the representative numbers for each species as a whole are proportionally within three sample firings of each other. This should provide a reasonable cross-section.

Mean moisture content varied from 19.62% (yellow poplar) to 31.12% (white oak) in the 96 total samples measured (Table 2, Fig. 1).

TABLE 1. Distribution of samples for which data were usable to determine calories per gram.

Type of tree	Tree					Total
	A	B	C	D	E	
Shagbark hickory	3	2	2	4	4	15
Yellow poplar	4	3	2	2	3	14
Black oak[1]	3	3	1	3		10
Flowering dogwood	3	3	3	2	3	14
White oak	3	5	2	3	3	16

[1]Only four trees were examined.

TABLE 2. Mean moisture content in percent for each tree and for each type of tree. Four samples from each tree were tested.

Type of tree	Tree					Mean
	A	B	C	D	E	
Shagbark hickory	27.89	26.73	26.66	27.18	25.93	26.88
Yellow poplar	19.31	19.53	19.82	19.81	19.65	19.62
Black oak	23.18	24.84	22.56	20.95		22.88
Flowering dogwood	25.61	29.05	24.94	25.62	28.46	26.73
White oak	31.98	31.67	32.02	28.00	31.91	31.12

Moisture content was significantly different among species ($F = 129.17$, $d.f. = 4,91$). In this particular group of samples, the five species appea to release and absorb moisture in different ways. However, further study is needed to determine the mechanisms involved. The mean (±1 *SD* moisture content as a percentage of the entire weight of a wood sample in the air-dried state is shown in Fig. 2. The total air-dry weight of given sample is 100%.

Mean calories per gram (±1 *SD*) for the individual trees ar illustrated in Fig. 3. Generally, the calories per gram for the trees ar close to the mean of 4,440 cal/g for all 69 samples. The mean (±1 *SD* maximum, and minimum value for each species are presented in Tabl 3. The range of calories for the usable data was 4,011 to 4,854. Th mean number of calories per gram was greatest for flowering dogwoo and lowest for yellow poplar (Table 3), with a difference of only 167 ca g. Calories per gram for these five species of hardwoods in this stud did not vary significantly ($P > 0.05$, $F < 1.00$).

The relationship of moisture content to the efficiency percent of th wood has been determined through experimentation on various woodfue at differing moisture contents in a controlled furnace (Fig. 4; Ince, 1977 The effect of hydrogen contained in the wood was also taken int account. However, the heat losses due to hydrogen, dry gas and exce air, and miscellaneous causes remained relatively constant. The moi ture content was the variable that dynamically affected the efficiency the wood (Ince, 1977). Even at 0% moisture content, the wood will

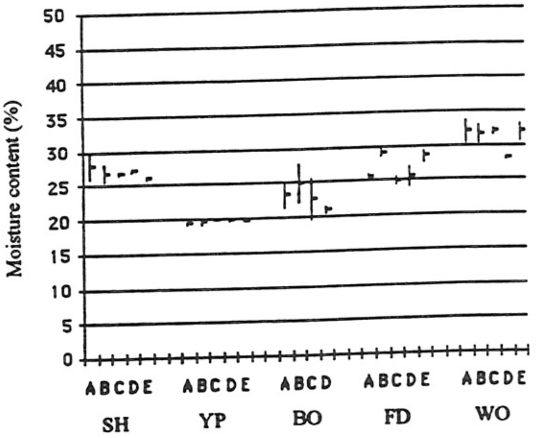

FIG. 1. Mean moisture content (±1 *SD*) for individual trees. S shagbark hickory, YP = yellow poplar, BO = black oak, FD = flower dogwood, and WO = white oak.

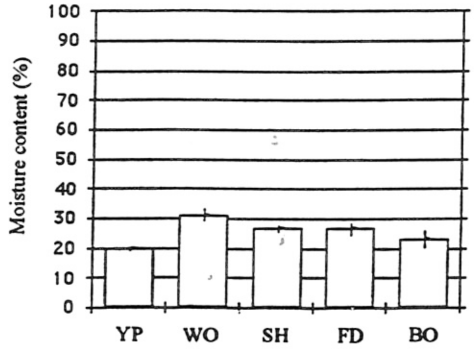

FIG. 2. Mean moisture content (±1 *SD*) as a percentage of the total weight of a wood sample in the air-dried state. SH = shagbark hickory, YP = yellow poplar, BO = black oak, FD = flowering dogwood, and WO = white oak.

TABLE 3. Mean (±1 *SD*), maximum, and minimum calories pe gram for each type of tree.

Type of tree	Calories/g		
	Mean (±1 *SD*)	Maximum	Minimum
Shagbark hickory	4,401 (±172)	4,586	4,054
Yellow poplar	4,367 (±157)	4,618	4,084
Black oak	4,424 (±146)	4,685	4,229
Flowering dogwood	4,534 (±145)	4,845	4,394
White oak	4,413 (±220)	4,854	4,011

only about 77% efficient. This is due to the causes previously stated. Mean moisture content of each species was compared to the efficiency percent curve (Fig. 4) to determine the value to multiply the total BTU per cord by to arrive at the effective BTU per cord.

Mean density in grams per cubic centimeter for 94 samples from the five species were as follows: 0.48223993 for yellow poplar; 0.56746445 for white oak; 0.59500136 for shagbark hickory; 0.59656240 for flowering dogwood; 0.62331966 for black oak. Differences among species was statistically significant ($F = 27.21$, *d.f.* = 4,89). These data are used to determine the amount of energy contained in a certain volume or, ultimately in this case, BTU per cord.

To find effective BTU per cord, one must start with calories per gram, grams per cubic centimeter, moisture content, efficiency percent, and average cubic feet of solid wood per cord. The calories per gram, the grams per cubic centimeter, and the moisture content were determined by experimentation in the present study. The efficiency percent was obtained from Fig. 4. The average cubic feet of solid wood per cord is 90 to 95 (Baker, 1983); 92.5 cubic feet of solid wood per cord will be used in the present study. The following mathematical arguments were used to arrive at the final effective BTU per cord for each species. Pounds per cubic foot = (grams per cubic centimeter)(62.43) and BTU per pound = (calories per gram)(1.799773234); therefore, BTU per cubic foot = (grams per cubic centimeter)(calories per gram)(112.3598435) and total BTU per cord = (BTU per cubic foot)(92.5). The efficiency percent is taken from Fig. 4; therefore, total BTU per cord = (grams per cubic centimeter)(calories per gram)(112.3598435)(92.5) and effective BTU per cord = (total BTU per cord)(efficiency percent). Total ($F = 16.86$, *d.f.* = 4, 62) and effective ($F = 15.11$, *d.f.* = 4, 62) BTU per cord (Ambrose and Ambrose, 1987) showed statistically significant differences among the five species of hardwoods.

The relationship of the moisture content as a proportion of the total weight of air-dried wood, the density in grams per cubic centimeter, the total BTU per cord, and the effective BTU per cord is illustrated in Fig. 5. Density, or grams per cubic centimeter, appears to have the greatest effect on total BTU per cord as the curves for these data are similar. The

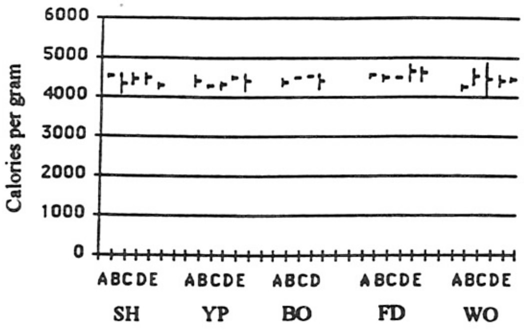

FIG. 3. Calories per gram (±1 *SD*) for individual trees. SH = shagbark hickory, YP = yellow poplar, BO = black oak, FD = flowering dogwood, and WO = white oak.

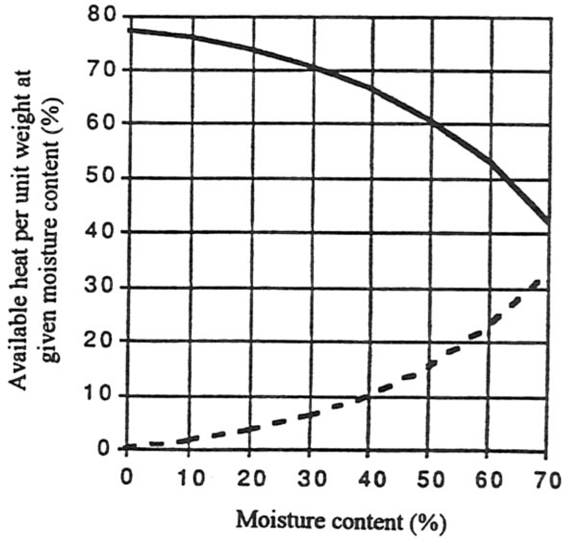

FIG. 4. Relationship of moisture content to available heat per weight (Ince, 1977). Dashed line = percent moisture content; solid line = percent of efficiency.

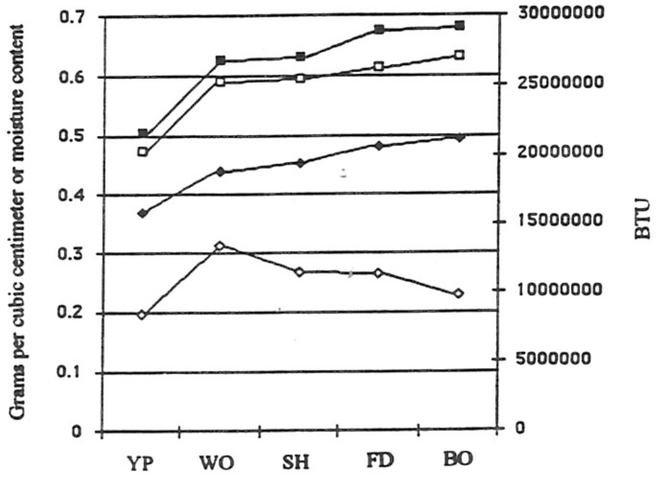

FIG. 5. Mean grams per cubic centimeter (open squares), mean moisture content in percent (open diamonds), total BTU per cord (solid squares), and effective BTU per cord (solid diamonds). SH = shagbark hickory, YP = yellow poplar, BO = black oak, FD = flowering dogwood, and WO = white oak. The curve for effective BTU per cord indicates the relative available heat per volume of wood or the woodfuel value.

greatest divergence in these two curves occus in dogwood where there is a larger total BTU per cord to density ratio. This is supported in the data obtained for mean calories per gram which was 4,534 for flowering dogwood and 4,424 for black oak, the next highest. Since black oak was the most dense wood in the present study, this resulted in it having the highest total BTU per cord. Moisture content does affect the available energy in a cord of wood or, in this case, effective BTU per cord. When moisture content increases the difference between total BTU per cord and effective BTU per cord increases (Fig. 5).

Woodfuel is prepared by the user with a great deal of time and effort or on a dollars-per-cord basis. The price per cord, or time and effort per cord, can be compared to the relative heat available per cord to determine which species provides the most heat per dollar or most heat per time and effort. Therefore, the best woodfuel value for typical air-dried hardwoods may be realized. The present study shows significant differences in the effective BTU per cord among shagbark hickory, yellow poplar, black oak, flowering dogwood, and white oak that were left loosely stacked on the harvest site. Species with similar calories per gram, lower air-dry moisture content, and a higher oven-dry density have the higher effective BTU per cord. Results indicate that black oak is a better fuel value than the other four species and should be given this consideration when selecting trees for harvest or when purchasing woodfuel by the cord. Further study is encouraged in this area, especially studies including bark, using larger numbers of specimens, and with more mature and more diverse species.

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