BIOMASS AND GASIFICATION PROPERTIES OF YOUNG CATALPA TREES

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ABSTRACT

Studies were conducted to establish baseline information for use in characterizing catalpa (*Catalpa speciosa*) as an energy or fiber feedstock. Characteristics of whole-tree chips and wood from 7-year-old trees were similar to those of soft hardwoods: the calorific value was 18.4 kJ/g (4,401 cal/g); the fiber length was relatively short (0.63 mm); the ash content was 0.38%; and the individual whole-tree chip specific gravity was 0.39. Specific gravity values for the wood only were 0.42 at the tree base, 0.40 at DBH, and 0.38 for middle level-branch wood (all based on green volume). Air-blown gasification of whole-tree catalpa chips in a downdraft gasifier produced a low energy gas (4.8–5.2 MJ/m^3). Trials at dry-chip feed rates of 95 and 123 kg/h resulted in an average gas-to-feed mass ratio of 2.6 and average char yield of 2.5% of the dry wood fed. Annual oven-dry biomass yield at an upland site in eastern Kansas was 1.9 t/ha for an operational-sized plantation (1/2 ha) with a stocking density of 2,980 trees/ha.

Keywords: Catalpa, *Catalpa speciosa,* wood energy, specific gravity, calorific value, fiber length, gasification, biomass yield.

INTRODUCTION

Potential exists for woody biomass to have a greater role as an appealing energy source; its use in the United States has increased and caused fuelwood shortages in the recent past (Clarke 1985). Much of the timber cut in the Great Plains is used for fuelwood, and about three-fourths of the annual cut in Kansas is for this purpose (Raile and Spencer 1984). Forest plantations of rapidly growing hardwoods, managed intensively for biomass production, could contribute significantly to future alternative energy supplies. Numerous tree species should be evaluated to determine their potential to overcome this shortage. Catalpa (*Catalpa speciosa* L.) is one species that appears promising because of its good growth in the Plains environment.

Catalpa historically has been used extensively for fence posts in the Plains states and to some extent as stovewood because of its durability (Roberts 1902). Prolific sprouting ability at the stump after being cut (Scott 1912) makes catalpa a potential tree species for the short-rotation forestry (SRF) woody crop concept.

Although catalpa has potential for energy production and perhaps other technological uses, many basic properties of young trees have not been characterized, thus limiting comparison to other woody plants.

The objective of this study was to establish

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baseline information for characterizing young catalpa as an energy or fiber feedstock and to provide limited empirical biomass yield data on upland sites in the central Great Plains.

MATERIALS AND METHODS

Planting site and characterization

This study was conducted in eastern Kansas on an upland site, which had been in native pasture grasses for 15 years. The soil was classified in the Morril and/or Pawnee series (fine-loam, mixed or fine montmorillonitic, mesic, Typic Argiudolls) and consisted of 30 cm of silt loam soils underlain by clay loam on 5% slopes. Numerous broadleaf tree species were planted on this site to determine yield variations.

A 1/2-ha plot planted to catalpa at 1.2 × 2.7 m (2,980 trees/ha) was established to evaluate production and for later harvesting studies. The plantation was treated with a herbicide—Casoron combined with cultivation during the first and second growing seasons. No subsequent weed control practices were applied other than annual mowing for fire prevention reasons. Fourth-year growth results (Geyer and Naughton 1980), production and harvesting costs (Naughton 1985), and wood characterizations (Geyer et al. 1987, 1994; Geyer and Walawender 1997) have been published previously for other species in this planting.

Nondestructive annual measurements of height and diameter were used with individual tree weight curves (dormant) to determine dry weight area yields. These curves (Geyer 1993) have been developed from destructive sampling of 47 trees at similar spacings, giving the following equation with a correlation coefficient of 0.889: as $\log_{10}W = 2.162 + 0.861 \log_{10}D^2H$, where W is OVD tree weight (kg), D is base diameter (cm) and H is total height (m). We have found these variable values to be different for black locust, silver maple, Siberian elm (Geyer et al. 1987, 1994; Geyer and Walawender 1997), and 10 other hardwood tree species not yet reported. Individual tree weights, incorporating survival at seven years and planting density, were used to calculate yield.

Sampling.—Ten sample trees were collected for characterization, chipped with a MORBARK EEGER BEEVER chipper, and thoroughly mixed. Twenty random samples (about 0.5 kg) were taken from the fresh chip pile for chipwood characterization. Also, disks were taken from 15 trees of 5-cm thickness at base, DBH, and middle branch levels and analyzed separately for determining specific gravity.

Calorimetry.—The calorific value was determined for ground, oven-dried, whole-tree chips, according to ASTM Standard D 2015-77 (1981). The material used for the evaluation was ground to pass through a 20-mesh screen to achieve complete combustion and good pellet cohesion (Neenan and Steinbeck 1979). Thirty samples, each consisting of approximately one gram of milled material, were pressed into pellets and combusted in a Parr 1341 adiabatic calorimeter. Correction factors for the formation of acids were not included in the gross heat of combustion calculations (Murphey and Cutter 1974; Barnes and Sinclair 1984). However, calorific values were corrected for moisture regained during storage.

Specific gravity.—The specific gravity was determined on the basis of oven-dried weight per green volume of the individual disk segment (1/4 section void of branch traces). Green volumes were obtained by soaking disk segments for 2 days in water until constant volume was achieved. Excess moisture was removed from the surface of the segment with a damp cloth, and each segment's water displacement (volume) was measured. Then the segments were oven-dried at 104°C for 3 to 4 days to constant weight to determine the dry sample weight. Also, 113 chips were chosen randomly from a chip pile composed of 10 trees to determine specific gravity of individual chips.

Ash content.—Ten samples of oven-dried, ground, whole-tree chips were ashed in a muffle furnace. The ash content was determined following the ashing procedure described in ASTM Standard D 1102-84 (1995).

Fiber length.—Fiber length was determined using a method similar to that of Tsoumis (1968). Matchstick-size slivers taken from chips were macerated, and separate fibers were projected with a Mark VII microprojector for measurement. Five fibers on each of 20 slides were measured and recorded.

Gasification studies

Chip source.—Approximately 150 kg of catalpa chips for the gasification studies were obtained from additional 7-year-old trees with trunk diameters ranging from 5 to 15 cm. The trees were cut and stored outdoors for more than a year before they were chipped. The whole-tree chips were obtained from stems and branches; they contained a substantial portion of bark. Values for the other chip characterizations were made from fresh chips.

Chemical and physical properties of chips.—The properties determined for the chips used in gasification were elemental analysis (ultimate analysis) of dry material; chemical constituents (cellulose, hemicellulose, and lignin); moisture content; heating value; average chip thickness; chip bulk voidage; chip bulk density; dry wood density (dry wood and dry volume basis); and wood internal voidage. Details of the measurement procedures have been given by Walawender et al. (1988).

Bulk voidage and bulk density are properties associated with an ensemble of chips and depend on the extent of packing. These properties were obtained for the loose packing associated with dumping the chips into a container. This condition is characteristic of the packing of chips in the top section of the downdraft gasifier.

The wood internal voidage was estimated from the following relationship:

$$\text{Wood Internal Voidage} = 1 - \frac{\text{Dry Wood Density}}{\text{Density of Wood Cell Material}}$$

The density of wood cell material is relatively independent of tree species; the specific gravity is approximately 1.5 (Panshin and de Zeeuw 1970).

Gasification.—Gasification studies were conducted with the Buck Rogers Gasifier. A description of the air-blown downdraft gasifier and the measurement and computational procedures have been given by Walawender et al. (1988). Two trials were conducted, one at a low fan rotation speed of 1,793 rpm and one at a high fan rotation speed of 2,560 rpm; both used a grate rotation speed of 3 rph.

Direct measurements consisted of wet feed rate, char rate, gas composition, and condensate-to-dry gas ratio. Material balance procedures (Walawender et al. 1988) were used to determine dry air input rate, dry product gas rate, and water output rate.

Results were expressed in terms of mass ratios to dry feed, such as the air-to-feed and gas-to-feed ratios. Because char yield is typically small, it is expressed as a percentage of dry feed. Other results consisted of cold gas efficiency, mass conversion efficiency, and energy output rate. All of the above performance measures have been defined by Walawender et al. (1988).

RESULTS AND DISCUSSION

Properties of whole-tree chips

All of the wood properties determined are summarized in Table 1. The average calorific value of catalpa whole-tree chips was 18.4 kJ/g (4,401 cal/g). This value is within the ranges for hardwoods quoted by Arola (1976), which varied from 16.3 kJ/g (3,886 cal/g) for white ash to 23.9 kJ/g (5,728 cal/g) for birch.

Specific gravity (SG) of the individual whole-tree chips was 0.39, which is the same as the total weighted (by dry weight) value of wood and bark combined at DBH. Geyer (1981) reported that SG ranged from 0.33 to 0.42 for stems, branches, bark, and buds (all combined) from 3-year-old trees of maple, sycamore, willow, black alder, boxelder, and two sources of cottonwood.

TABLE 1. *Properties of whole-tree chip, and disk segments of 7-year-old catalpa.*

Property	Mean	Minimum	Maximum	Std. dev.	Sample size
Whole-tree chips					
Calorific value (kJ/g)	18.4	13.5	21.1	1.2	30
Ash content (% ash)	0.38	0.24	0.52	0.01	10
Wood fiber length (mm)	0.63	0.37	0.81	0.10	100
Specific gravity (SG)	0.39	0.29	0.49	0.04	113
Disk segment[1/]					
Base calorific (kJ/g)	18.7	18.2	20.3	—	10
Base bark SG (gr. vol.)	0.23	0.16	0.28	0.04	15
Base wood SG	0.42	0.39	0.46	0.02	15
Base combined SG b+w[2/]	0.40	0.38	0.45	0.02	15
% wood (volume)	0.92	0.89	0.96	0.02	15
DBH calorific (kJ/g)	17.7	13.5	19.6	—	10
DBH bark SG (gr. vol.)	0.29	0.24	0.36	0.04	15
DBH wood SG	0.40	0.29	0.47	0.04	15
DBH combined SG b+w[2/]	0.39	0.29	0.45	0.03	15
% wood (volume)	0.90	0.85	0.93	0.02	15
Branch calorific (kJ/g)	18.8	18.0	21.2	—	10
Branch bark SG (gr. vol.)	0.31	0.26	0.37	0.04	15
Branch wood SG	0.38	0.33	0.43	0.03	15
Branch combined SG b+w[2/]	0.37	0.32	0.41	0.02	15
% wood (volume)	0.86	0.80	0.90	0.03	15

[1/] Mean values between bark SG, wood SG, and % wood volume each differ significantly at the 5% level. Also, the base values of each differ from the branch values at the 5% level.
[2/] Combined weighted average of above bark and wood SG based on dry weight percentage.

The mean ash content of whole-tree chips of catalpa was 0.38% based on oven-dry weight. Normally, ash content of wood from various tree species ranges from 0.1 to 0.5% (Panshin and de Zeeuw 1970). However, bark ash content can be as much as 10 times greater (Jenson et al. 1963). Therefore, one can expect the ash content of whole-tree chips (containing wood and bark) to fall between the two values, depending upon the percentage of each constituent.

Properties of disk segments

Catalpa's average heating value was 6.8% lower than the average of 19.7 (4,722 cal/g) reported for hardwoods (Panshin and de Zeeuw 1980) but nearly the same as the 18.7 (4,476 cal/g) reported for several Great Plains hardwood seedlings (Geyer 1981), thus reflecting the inclusion of bark in our sample disks as compared to wood only values reported in the literature. Panshin and de Zeeuw (1980) comment that the value of heat of combustion bears little relationship to a particular kind of wood and varies from 5 to 8% at a maximum.

The specific gravity (SG) of our bark samples ranged from 0.23 to 0.31 (Table 1) and was significantly lower (5% level) than the wood SG. Wood and bark SG at the base also differed (5% level) from the wood and bark SG at the branch height.

Catalpa wood is moderately light, with a bole-wood SG of 0.39 to 0.40 based on oven-dry weight and green volume of our disk samples of bark and wood combined (Table 1). This was close to the values reported by Panshin and de Zeeuw (1980) for catalpa of 0.42 based on oven-dried weight and volume or about 0.38 based on green volume.

The average wood fiber length of 0.63 mm for catalpa is among the shorter lengths for the hardwoods. Panshin and de Zeeuw (1980) reported catalpa fiber length to be 0.64 mm.

Gasification studies

The chemical and physical properties of the whole-tree chips containing bark used for gas-

saccharinum L.), which often is considered for short rotation forestry (SRF) plantings in the United States. The maple planted at the same stocking density grew at a rate of 4.94 t/ha/yr after 7 years (Table 4), which is 2.6 times greater than the rate at which catalpa grew during the same period of time on essentially the same site. Block plantings are more representative of field industrial planting operations and give lower yields than small research plots. The oven-dry biomass yield found on small research plots at the same site used in a previous study (Geyer and Walawender 1997) was 30% less for silver maple than in the 1-ha-sized block planting. This difference in biomass production is probably due to site heterogeneity, variation caused by weed control effectiveness, and pockets of missing trees.

CONCLUSIONS

The data presented for catalpa suggest:

1) Whole-tree chip properties are similar to those of other soft hardwoods, such as cottonwood and willow, except that fiber length is shorter.
2) Air-blown downdraft gasification produces a low-energy-content gas with low char yield.
3) This species does not produce biomass yields as high as silver maple when grown in short-rotation forestry plantations.

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