BIOMASS PROPERTIES AND GASIFICATION BEHAVIOR OF YOUNG SILVER MAPLE TREES

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ABSTRACT

Studies were conducted to establish baseline information for use in characterizing silver maple as an energy or fiber feedstock. Biomass properties were determined. Calorific value (18.26 kJ/g) and specific gravity (0.44) green volume of silver maple are similar to those of maples; and its fiber length is relatively short (0.74 mm). Ash content was 0.40%.

Air-blown gasification of whole-tree silver maple chips in a downdraft gasifier produced a low energy gas (3.7–4.4 MJ/m^3). Trials at dry chip rates of 88 and 127 kg/h resulted in an average gas-to-feed mass ratio of 3.0 and an average char yield of 2.9% of the dry wood fed.

Oven-dry biomass yields were 11.1 t/ha annually at 7,000 tree/ha.

Keywords: Silver maple, *Acer saccharinum,* wood energy, specific gravity, heating value, fiber length, gasification, and biomass yield.

Woody biomass is an appealing energy source, and its use in the United States has increased dramatically in the last few decades. Roundwood harvested for fuel in the United States was higher in 1986 than at any time since before World War II, more than six times the production of 1970 (Haynes 1990). Much of the timber cut in the Plains States is used for fuelwood. In Kansas, it has been estimated that three-fourths of the annual cut is for fuelwood (Raile and Spencer 1984). Forest plantations of rapidly growing hardwoods, managed intensively for biomass production, could contribute significantly to future alternative energy supplies.

Fuelwood shortages are a national and global problem (Clarke 1985). Numerous tree species should be evaluated to determine their potential to overcome this shortage. Silver maple (*Acer saccaharinum* L.) is one species that appears promising because of its good growth on alluvial sites.

Although silver maple is a potential tree species for energy production and perhaps other technological uses, many basic properties of young trees in this species have not been characterized, thus limiting comparison to other woody plants. The objective of this report is to establish baseline information for characterizing young silver maple as an energy or fiber feedstock and to provide limited empirical yield data on upland sites in the Central Plains.

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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 consists of 0.3 m of silt loam soils underlain by clay loam on 5% slopes. Numerous broadleaf tree species were planted to determine plant-density yield variations. A Nelder-wheel (Namkoong 1965) consisting of 210 trees per species, replicated twice, was used to provide five planting densities ranging from 1,400 to 7,000 trees per hectare with two border rings. An additional 1.5 hectare plot planted to silver maple at 1.2 × 2.4 m (3,470 trees/ha) was established for harvesting studies.

Cultivation was used to control weeds during the first and second growing seasons in the "wheel" density trials, whereas a herbicide/cultivation combination was used in the larger plot. 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) have been previously published for these plantings.

Nondestructive annual height and diameter measurements 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 0 trees at similar spacings, giving the following equation: $\log_{10}W = 2.067 + 0.944 \log_{10}D^2H$, where W is OD tree weight (kg), D is base diameter (m), and H is total height (m). Individual tree weights, incorporating survival at 7 years and planting density, were used to calculate yield.

Sampling.—Ten sample trees were collected for characterization from randomly selected tree bundles (one tree per bundle) during the 1984–1985 dormant season from a recently harvested 7-year-old, short-rotation "energy plantation" growing adjacent to the Nelder-wheel growth plots. Also disks were taken from 15 additional trees for determining specific gravity. Sample trees were chipped using a MORBARK EEGER BEEVER® chipper and then were thoroughly mixed. Twenty random samples (about 0.5 kg in total) were taken from the chip pile for wood characterization.

Calorimetry.—The heating value was determined for ground, oven-dried, whole tree chips, according to ASTM STANDARD D 2015-77 (1981a). 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). Eighty 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, heating values were corrected for moisture regained during storage.

Specific gravity.—Disks of 50-mm thickness were taken from 15 additional trees at base, breast height, and middle branch levels for analysis. The specific gravity was determined on the basis of green volume of the individual disk segment. Green volumes were obtained by soaking disk segments for 10 days in water until constant volume was achieved. Excess moisture was removed from the surface of the sample with a damp cloth, and each sample's water displacement (volume) was measured. They then were oven-dried to constant weight (3 to 4 days) at 104°C and weighed to determine the dry sample weight. Also, 100 chips were chosen randomly for individual chip specific gravity determinations.

Ash content.—Ten samples of oven-dried, ground, whole-tree chip particles were ashed in a muffle furnace. The ash content was determined following the ashing procedure described in ASTM STANDARD D 1102-56 (1981b).

Fiber length.—Fiber length was determined using a method similar to that of Berlyn and Miksche (1976). Matchstick-size slivers taken from chips were placed in a solution of equal parts glacial acetic acid and hydrogen peroxide (30% volume) and heated in an oven at 60°C for 48 hours. Fibers then were separated, placed on slides, and projected onto a calibrated bulls-eye ring using a Mark VII micro-projector. Five fibers on each of 20 slides were measured and recorded.

Gasification studies

Chip source.—Approximately 150 kg of silver maple chips for the gasification studies were obtained from additional 5-year-old trees with trunk diameters ranging from 50 to 150 mm. 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.

Chip chemical and physical properties.—A number of properties were determined for the whole-tree chips. These consisted of elemental analysis (ultimate analysis) of dry material; chemical constituents on nonextractive free material (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); 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 packing associated with dumping the chips into a container, i.e., loose packing. This condition is characteristic of the packing of chips in the top section of the 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; it has a specific gravity of approximately 1.5 (Panshin and deZeeuw 1980).

Gasification.—Gasification studies were conducted with the Buck Rogers "Gasifire." A description of the air-blown downdraft gasifier, along with the measurement and computational procedures, has 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 with 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

Wood properties

All of the wood properties determined are summarized in Table 1. Average calorific value of silver maple whole-tree chips was 18.26 kJ/g. This value is within the range for hardwoods quoted by Arola (1976), which varied from 16.26 kJ/g for white ash to 23.97 kJ/g for birch.

Silver maple's average heating value was 7.5% lower than the average of 19.76 kJ/g reported for hardwoods (Panshin and deZeeuw 1980). However, it was higher than the 18.73 kJ/g reported for several Great Plains hardwood seedlings (Geyer 1981).

Silver maple wood is moderately heavy, with a specific gravity (SG) of 0.44 based on oven-dry weight and green volume of our disk samples. This was within the range reported by Panshin and deZeeuw (1980) for soft maple of 0.51–0.55 based on oven-dry weight and vol-

TABLE 1. *Wood and bark properties of 7-year-old silver maple.*

Property		Mean	Minimum	Maximum	Std. dev.	Sample size
Heating value (kJ/g)		18.26	16.70	19.40	13.40	80
Ash content (% ash)		0.40	0.31	0.51	0.08	10
Fiber length (mm)		0.74	0.61	0.90	6.19	100
Specific gravity (gr. vol)						
Base	bark	0.53	0.41	0.61	0.04	15
	wood	0.45	0.41	0.51	0.03	15
DBH	bark[1]	0.53	0.40	0.62	0.06	15
	wood	0.43	0.38	0.46	0.02	15
Branch	bark	0.51	0.39	0.62	0.07	15
	wood	0.41	0.36	0.50	0.04	15
Combined bark + wood[2]		0.44	0.38	0.52	0.03	45
Chips		0.42	0.36	0.50	0.03	100

[1] Mean values between wood and bark differ significantly at the 5% level; base wood specific gravity significantly different from others.
[2] Combined weighted average of above based on dry weight percentage.

ume, or about 0.44–0.49, based on green volume. Geyer (1978) reported that SG for 3-year-old trees was 0.41 for stems, branches, bark, and buds.

The ash content of silver maple had a mean value of 0.40% based on oven-dry weight. Normally, ash content of tree species ranges from 0.1 to 0.5% for wood (Panshin and deZeeuw 1980). Bark ash content, however, can be as much as 10 times greater than that of wood (Jenson et al. 1963). Therefore, one can expect the ash content of whole tree chips (containing wood and bark) to be between the two values, depending upon the percentage of each constituent.

The average fiber length of 0.74 mm for young silver maple is among the shorter lengths of the hardwoods. Panshin and deZeeuw (1980) report silver maple fiber length to be 0.76 mm.

Gasification studies

The chemical and physical properties of the whole-tree chips used for gasification are summarized in Table 2. Note that the wood density presented is on a dry wood and dry volume basis. The ash content of 0.95% and the heating value of 19.50 kJ/g are higher than the values given earlier for wood because of the presence of bark from both stems and branches in these chips. The cellulose content (60.15%) was relatively high due to hemicellulose deterioration as compared to 40.9% shown by Panshin and deZeeuw (1980) for mature trees.

The results from the gasification trials are summarized in Table 3. The grate rotation speed of 3 rph was found previously to be near optimal for the gasifier (Walawender et al. 1988). This is reflected by the relatively low char yield of 2–3%. The air-to-feed mass ratios for the two trials are somewhat greater than the optimal range of 1.6 to 1.7. This increases the gas-to-feed mass ratio. However, the gas

TABLE 2. *Chemical and physical properties of whole-tree chips of young silver maple.*

Elemental composition (dry %)*				
C	H	O	N	Ash
48.12	5.93	45.49	0.46	0.95
Chemical constituents (%)+				
Cellulose		Hemicellulose		Lignin
60.15		17.71		11.61
Heating value (kJ/g)+			Average chip thickness (mm)+	
19.50			58	
Chip bulk voidage+			Chip bulk density (kg/m³)+	
0.44			109	
Dry wood density (kg/m³)+			Wood internal voidage	
530			0.65	

* Mean values for 10 determinations.
\+ Mean values for 5 determinations.

TABLE 3. *Downdraft gasification results for whole tree-chips of young silver maple.*

Run no.	Wet feed rate (kg/h)	Moisture content (%-wet)	Dry feed rate (kg/h)	Air-to-feed ratio	Gas-to-feed ratio	Char yield (%)
5002	93.78	6.5	87.68	2.15	2.46	3.22
5006	136.98	7.5	126.71	2.77	3.44	2.51

Run no.	Mass conversion efficiency	Cold gas efficiency	Gas higher heating value (MJ/m^3)	Energy output rate (MJ/h)
5002	0.91	0.56	4.38	982
5006	0.89	0.56	3.68	1,409

Run no.	Dry gas composition (%)			
	H_2	CO_2	N_2	CO
5002	10.8	12.7	54.6	21.0
5006	11.9	13.6	59.7	13.8

TABLE 4. *Mean tree growth characteristics for plant density trials of 7-year-old silver maple grown in eastern Kansas on upland loamy prairie soils.*

Tree density (no./ha)	Survival (%)	Total height (m)	Stump diameter @100 mm (mm)	Annual oven-dry yield of dormant material (tonne/ha)
7,000	98	7.5[1]	98[1]	11.2[1]
4,700	100	7.3	96	7.7
3,200	100	8.1	116	7.0
2,100	100	8.3	137	5.6
1,400	100	8.2	140	5.3

[1] The confidence intervals at the "t" 0.05 level for the lowest and highest two densities did not overlap, thus indicating a significant difference.

has a relatively high nitrogen content, which, in turn, gives a lower heating value. An increase in the fan rotation speed increased the wood feed rate, which subsequently increases the energy output rate; this agrees with previously reported observations (Walawender et al. 1988). The energy output rate of the order of 1,000 mJ/h (about 1 million Btu/h) is suitable for small- to moderate-scale industrial operations.

Biomass yield

Planting density substantially affected all tree growth characteristics, except total height and survival (Table 4). Survival remained nearly 100% after 7 years. Annual oven-dry weight yields increased with greater planting density. The highest planting density (7,000 trees/ha) produced more than twice the yield of the lowest tree density (1,400 tree/ha). Because of the limited sample size, confidence intervals were calculated only for yield at the widest and narrowest spacing. They did not overlap at "t" 0.05 value, thus indicating that the difference is significant. The mean annual increment (MAI) growth rate of dry wood at 7 years is still increasing (20% greater than at 4 years). This indicates that the biological harvest age has not been reached. Average annual growth rates are greater than those previously reported for several younger-aged hardwood species in Kansas (Geyer 1981).

CONCLUSIONS

The data presented for silver maple suggest that:

1) Whole-tree chip properties are similar to those of other soft elms, except that fiber length is shorter than most hardwoods.
2) Air-blown downdraft gasification produces a low energy content gas with a relatively low char yield.
3) This species can produce high biomass yields when grown in short-rotation forestry plantations; however, maximum biological growth rates have not yet been achieved at seven years, even at a close planting density of 7,000 trees/hectare.

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