COMPARISON OF SELECTED FUEL AND CHEMICAL CONTENT VALUES FOR SEVEN *POPULUS* HYBRID CLONES[1]

Paul R. Blankenhorn, Todd W. Bowersox, Kenneth M. Kuklewski, and *Gwen L. Stimely*

Professor of Wood Technology, Associate Professor of Silviculture
and Research Assistants
School of Forest Resources, The Pennsylvania State University
University Park, PA 16802

and

Wayne K. Murphey

Cooperative State Research Service, USDA
Washington, DC 20250

(Received July 1983)

ABSTRACT

Fuel and chemical content values were determined for seven *Populus* clones by component (wood, bark, and wood/bark specimens) and tissue age (1 to 8 years old). The fuel and chemical content values obtained included: gross heat of combustion, extractives, holocellulose, alpha-cellulose, lignin, and ash. In general, analysis of the data for the wood, bark, and wood/bark specimens indicated that: 1) wood was higher in holocellulose and alpha-cellulose content than bark; 2) bark was higher in gross heat of combustion, lignin, extractive, and ash content values than wood; and 3) combined wood/bark fuel and chemical content values were usually between the individual values for the wood and bark.

Statistical analyses indicated that significant differences existed within and among clones. Within the wood, bark, and wood/bark specimens, tissue age influenced the chemical content values more than the parentage. Potential chemical yields derived from the seven *Populus* hybrid clones investigated will depend on component and age with limited parentage effects.

Keywords: *Populus* hybrids, gross heat of combustion, extractives, holocellulose, alpha-cellulose, lignin, ash.

INTRODUCTION

Biomass from intensively managed plantations is being considered as a future source of energy and chemicals. Utilization of short-rotation forest biomass for this purpose will depend on physical and chemical properties such as: 1) gross heat of combustion; 2) extractive content; 3) holocellulose content; 4) lignin content; 5) alpha-cellulose content; and 6) ash content. Data on the utilization of short-rotation forest biomass, particularly pulping characteristics, are beginning to appear in the literature (Anderson and Zsuffa 1975; Bendtsen 1978; Bendtsen

[1] The authors wish to thank L. E. Rishel, M. G. Sandala, J. R. Hazen, S. A. Wilson, and R. J. Stiener for their help in specimen preparation and conducting some of the over 3,200 tests needed to compile the data. This research was supported in part by funds from McIntire-Stennis Project 2380 and USDA Grant 59-2421-0-2-033-0. This paper was received for publication in August 1983 as paper No. 6748 in the Journal Series of the Pennsylvania Agriculture Experiment Station.

TABLE 1. *Parentage of the seven* Populus *hybrids.*

Clone	Parentage	
	Female	Male
NE-49	*maximowiczii*	'Berolinensis'
NE-245	'Angulata'	*deltoides*
NE-252	'Angulata'	*trichocarpa*
NE-279	*nigra*	*laurifolia*
NE-302	'Betulifolia'	*trichocarpa*
NE-350	*deltoides*	*trichocarpa*
NE-388	*maximowiczii*	*trichocarpa*

et al. 1981; Bowersox et al. 1979; Cech et al. 1960; Cheng and Bensend 1979; Dawson et al. 1976; Geyer 1981; Holt and Murphey 1978; Hunt and Keays 1973; Laundrie and Berbee 1972; Marton et al. 1968; Murphey et al. 1979). These studies will help provide needed information to aid in species screening and product development.

Intensive culture of dense forest biomass plantations usually results in a large number of small-diameter trees per unit land area. Harvesting and processing of small-diameter trees differ from the traditional harvesting and processing techniques. One advantage in processing the short-rotation forest biomass is the uniform properties in a given clone. Measurement and comparison of the properties within a clone (by age) and among clones will aid in clonal selection and will establish basic data needed to utilize this forest biomass as a source of fuel or chemicals. The purpose of this study was to compare by age (1 to 8 years old) within and among seven *Populus* hybrid clones the gross heat of combustion, extractive content, holocellulose content, lignin content, alpha-cellulose content, and ash content values for wood, bark, and wood/bark specimens.

EXPERIMENTAL

Wood, bark, and wood/bark specimens were obtained by age (1 to 8 years old) from 8-year-old trees of seven *Populus* hybrids (parentages presented in Table 1) near the bud scar for a given age. Ten to fifteen trees from experimental plots for each clone were harvested, and the tissues at each age within each clone were combined to help account for any variations associated with the growing site. The wood and bark specimens were separated at each age. The wood/bark specimens were obtained as a cross-sectional disk from each sample tree at each age.

The seven *Populus* hybrids were planted on the same site at 0.6 by 0.6 m spacing in a Weikert shaly, silt loam soil located in central Pennsylvania. Soil from the Ap horizon was collected at the time the trees were planted and analyzed by the Soil Testing Laboratory of The Pennsylvania State University according to established procedures (Hinish et al. 1967). The Weikert soil series consists of material weathered from noncalcareous shale. Depth to bedrock where these specimens were obtained ranged from 0.5 to 0.7 m.

Weikert soils are used mainly for cultivated crops and are generally rated as fair in inherent fertility and very low to low in available moisture capacity. If the gently sloping site used in these plantings had been forested, site quality for oak would be rated as fair (oak site index 55–64). Specific nutrient levels for the central

TABLE 2. *Average analysis of the Ap horizon for a Weikert shaly, silt loam soil. Samples were collected at the time the trees were planted.*

	Measured[a]	Estimated[b] (kg/ha)
pH	6.0	—
Total nitrogen	0.17 (% by wt.)	3,810
Extractable phosphorus	7.1 (ppm)	16
Exchangeable potassium	0.27 (meq/100 g)	235
Exchangeable calcium	9.3 (meq/100 g)	4,169
Exchangeable magnesium	0.6 (meq/100 g)	163
Cation exchange capacity	14.1 (meq/100 g)	—

[a] All numbers are averages of 10 samples.
[b] Assumes 2,241,600 kg/ha for the Ap horizon.

Pennsylvania site at which the specimen trees were growing are presented in Table 2.

Data on wood, bark, and wood/bark specimens from seven *Populus* hybrid clones were obtained by age and included: 1) gross heat of combustion—ASTM

TABLE 3. *Summary of heat of combustion values for seven hybrid poplar clones by age and component.*

Age (yr)	Heat of combustion values (cal/g)*						
	350	252	279	245	302	388	49
				Wood			
1	4,509a	4,444	4,381bc	4,463	4,336	4,420	4,421
2	4,458ab	4,368	4,436ab	4,362	4,480	4,432	4,490
3	4,401ab	4,378	4,531a	4,317	4,329	4,424	4,430
4	4,552a	4,388	4,523a	4,315	4,308	4,354	4,366
5	4,341ab	4,336	4,521a	4,264	4,386	4,302	4,282
6	4,527Aa	4,460AB	4,527Aa	4,244C	4,464AB	4,300BC	4,430AB
7	4,429a	4,398	4,264c	4,283	4,336	4,348	4,306
8	4,529a	4,371	4,285bc	4,231	4,332	4,442	4,323
				Wood/bark			
1	4,442	4,455	4,342	4,429	4,510	4,408	4,375c
2	4,518AB	4,246C	4,647A	4,471ABC	4,402ABC	4,297BC	4,462ABCbc
3	4,556	4,372	4,648	4,483	4,467	4,343	4,512a
4	4,382	4,390	4,478	4,260	4,484	4,300	4,473abc
5	4,522	4,431	4,388	4,240	4,494	4,434	4,495ab
6	4,532	4,339	4,740	4,443	4,497	4,358	4,514abc
7	4,356	4,473	4,322	4,462	4,424	4,373	4,400c
8	4,498A	4,467A	4,245B	4,248B	4,435A	4,412A	4,508Aabc
				Bark			
1	4,741Aab	4,500BC	4,756A	4,646ABab	4,569ABab	4,311C	4,662ABbc
2	4,713Aab	4,497BC	4,686A	4,731Aa	4,624ABa	4,420C	4,575ABCc
3	4,879a	4,435	4,773	4,706a	4,677c	4,425	4,645bc
4	4,747Aab	4,543C	4,787A	4,721ABa	4,576BCab	4,422C	4,782Aa
5	4,589ABCbc	4,585BC	4,732AB	4,737Aa	4,625ABa	4,479C	4,657ABbc
6	4,382Cc	4,428BC	4,730A	4,632ABab	4,587ABCab	4,478BC	4,755Aab
7	4,648abc	4,554	4,527	4,741a	4,639a	4,622	4,532d
8	4,580bc	4,449	4,565	4,519b	4,507b	4,557	4,552Adc

* Heat of combustion values are an average of 3 replications. Means with the same letter (lower case—among ages within a tissue and clone; upper case—among clones for a given age) are not significantly different at the 0.05 level.

TABLE 4. *Summary of extractive content for seven hybrid poplar clones by age and component.*

Age (yr)	Extractive content (% ovendry component weight)*						
	350	252	279	245	302	388	49
				Wood			
1	8.54b	9.01a	8.44bc	8.73a	8.21	9.94a	7.21a
2	9.53a	8.39a	9.75a	8.41ab	8.88	8.82ab	7.37a
3	7.96BCb	8.20Bab	9.36Aab	7.44BCDbcd	7.10CD	8.14BCbc	6.62Da
4	7.82ABbc	6.81Cbc	8.08Ac	8.31Aab	8.27A	7.54ABCbcd	7.21BCa
5	7.13Cc	6.81Dbc	7.50Bc	6.40Ede	7.08CD	8.02Abc	5.76Fb
6	7.97Ab	5.42CDcd	6.96ABc	7.67ABabc	7.39ABC	6.87BCcde	5.15Db
7	6.04Bd	5.33Ccd	6.44ABd	6.06Be	6.73A	6.30ABde	5.60Cb
8	5.00Ce	5.21Cd	6.28Bd	6.66Acd	6.22B	5.80BCe	5.26Cb
				Wood/bark			
1	13.92Aa	15.46Aa	15.20Aa	11.10Ba	15.40Aa	14.46Aa	13.41Aa
2	12.31BCb	16.01Aa	13.42Bb	11.66BCab	13.05Bb	11.99BCc	10.65Cb
3	11.88BCb	14.63Aa	12.55Bbc	10.01CDbcd	11.42BCDc	13.01ABb	9.69Dc
4	10.07Cc	11.77Ab	12.21Acd	9.89Cbcd	11.07Bc	10.90Bde	9.62Cc
5	9.10Cd	10.56Bb	11.15ABde	9.77Cbcd	11.32Ac	11.13ABd	9.45Ccd
6	8.27Ce	10.58ABb	10.31Be	8.47Babc	10.63Abc	10.22Bef	8.65Cde
7	7.49Cf	9.46Bb	10.04ABe	9.16Bcd	9.46Bd	10.41Ade	7.69Cf
8	10.16Ac	9.84Ab	8.23Be	8.48Bd	7.97Be	9.55Af	7.94Bef
				Bark			
1	28.38ABCa	29.30ABa	30.36A	24.10BC	24.93BC	30.48A	23.42C
2	29.54ABa	25.90Eb	28.57BC	26.49DE	26.00CDE	30.95A	27.88BCD
3	28.27a	25.89b	25.70	21.38	23.47	33.01	36.53
4	29.53ABa	28.17ABa	26.96BC	22.60C	26.49BC	32.14A	27.41ABC
5	26.15CDb	26.99CDb	33.44A	25.44D	28.85BC	31.58AB	26.17CD
6	26.15Db	27.56Cab	30.48B	22.63F	27.93C	32.80A	24.31E
7	23.29Ec	26.84CDb	30.07B	23.41E	27.28C	33.24A	25.54D
8	22.69Cc	27.93ABa	28.83AB	23.17C	25.65BC	31.90A	23.09C

* Extractive content values are an average of 6 replications. Means with the same letter (lower case—among ages within a tissue and clone; upper case—among clones for a given age) are not significantly different at the 0.05 level.

TABLE 5. *Summary of holocellulose content for seven hybrid poplar clones by age and component.*

Age (yr)	Holocellulose content (% ovendry component weight)*						
	350	252	279	245	302	388	49
				Wood			
1	66.75Cbc	65.97Cd	72.37Bbc	72.33Bbc	77.27Aa	76.33AB	76.19AB
2	68.56CDabc	70.53BCc	64.28Dd	74.51ABabc	69.65BCb	70.93BC	78.77A
3	65.10Dc	73.89Babc	70.87Cc	74.15Babc	76.54ABa	75.18B	79.45A
4	65.51Cc	72.58ABbc	70.57BCc	76.40ABab	75.36ABa	73.02AB	78.93A
5	72.44ABab	74.15ABabc	68.35Bcd	76.95Aab	74.94Aa	74.00AB	78.59A
6	65.87Cbc	75.74Aab	71.69ABc	69.24BCc	73.52ABab	74.10A	75.23A
7	74.01Da	77.49ABCDa	79.05ABa	80.16Aa	74.32CDa	76.22BCD	77.92ABC
8	74.62a	76.63ab	78.04ab	72.09bc	73.40ab	72.37	75.59
				Wood/bark			
1	60.62	63.69b	62.87	65.56	62.62bcd	68.53	60.94c
2	63.96AB	57.61Bc	65.06A	69.61A	58.09Bd	70.93A	67.78Ab
3	62.85C	63.65BCb	62.72C	73.81A	66.00BCab	72.36A	67.10Bb
4	64.53C	64.23Cb	67.05C	68.54BC	63.59Cabc	72.59AB	74.18Aa
5	63.85B	64.40Bb	70.39A	73.38A	61.12Bcd	70.39A	74.42Aa
6	63.99BC	72.87Aa	64.72ABC	71.99AB	62.23Cbcd	71.06AB	66.96ABCb
7	67.83AB	71.97Aa	65.61B	72.11A	65.68Babc	73.45A	69.07ABb
8	65.51B	70.82Aa	69.51A	71.48A	68.77ABa	71.11A	70.52Ab
				Bark			
1	42.44Aab	39.47AB	33.58Bbc	42.92A	44.21A	39.03ABa	45.24Aab
2	36.99b	39.88	40.87a	38.40	38.56	35.82ab	36.58c
3	38.22b	41.70	35.53bc	39.37	39.62	40.10a	39.40bc
4	38.39b	39.59	37.76ab	43.20	39.25	37.80ab	44.46ab
5	41.40BCab	45.19AB	32.29Dc	41.00BC	39.74C	31.86Db	46.32Aa
6	42.31ab	43.98	36.53abc	40.87	41.77	34.65ab	46.28a
7	45.69Aa	41.58AB	33.50Cbc	36.70BC	42.43AB	31.22Cb	43.71ABab
8	45.65Aa	39.19C	36.98Cabc	36.92C	45.11AB	40.68BCa	43.72ABab

* Holocellulose content values are an average of 3 replications. Means with the same letter (lower case—among ages within a tissue and clone; upper case—among clones for a given age) are not significantly different at the 0.05 level.

TABLE 6. *Summary of alpha-cellulose content for seven hybrid poplar clones by age and component.*

Age (yr)	Alpha-cellulose content (% ovendry component extractive free weight)*						
	350	252	279	245	302	388	49
				Wood			
1	39.70	38.19	41.22	41.35	44.09	43.31	41.45
2	41.04	41.94	38.54	44.00	40.47	45.05	42.99
3	37.82	41.89	40.98	40.64	41.73	44.87	42.31
4	38.77	40.84	40.80	42.86	42.81	42.24	41.34
5	41.91	41.83	41.90	43.73	43.00	43.45	41.92
6	39.59	40.92	42.96	38.25	44.80	44.44	42.63
7	41.60	41.91	42.77	42.53	45.45	45.20	44.52
8	44.11	41.85	42.61	42.62	44.39	41.76	42.56
				Wood/bark			
1	36.17	38.59	33.55	37.58	37.60	38.84	34.33
2	32.90	34.61	35.76	33.64	35.56	39.73	39.05
3	33.44	39.45	39.18	35.41	37.07	42.89	38.74
4	34.53	37.72	40.42	39.55	37.46	40.27	39.35
5	34.66	37.58	38.69	40.86	37.19	40.69	41.97
6	43.19	40.79	39.33	43.48	40.96	42.81	31.27
7	42.46	40.94	40.01	39.75	40.20	38.13	36.80
8	34.80	41.12	38.92	31.87	41.14	36.25	36.23
				Bark			
1	25.59	28.77	26.94	28.49	30.92	31.27	28.31
2	21.02	30.29	24.59	27.16	29.51	30.45	29.78
3	23.75	31.83	24.74	29.38	30.68	27.42	26.91
4	24.32	33.74	26.63	29.55	26.35	27.62	27.48
5	25.48	33.29	25.65	33.73	32.32	28.27	29.46
6	25.93	36.44	30.03	33.76	29.94	27.99	28.65
7	25.09	34.84	27.13	30.84	29.53	27.33	28.55
8	21.47	35.10	30.79	30.06	29.86	28.97	29.81

* Alpha-cellulose content values are for 1 replication.

D 2015-66 (1980a) (Part 26); 2) extractive content—ASTM D 1105-79 (1980b) (Part 22); 3) holocellulose content (Browning 1967); 4) alpha-cellulose content—ASTM D 1103-77 (1980b) (Part 22); 5) lignin content—ASTM 1106-77 (1980b) (Part 22); and 6) ash content—ASTM 1102-78 (1980b) (Part 22). The standard tests were modified to accommodate smaller sized specimens because of the limited amount of early age material available from each clone. For all ages, the amount of material used for testing was identical. This permitted a relative comparison of the data to determine any effects associated with clone or age.

Chemical analysis of bark may be difficult because of suberin and other waxlike substances in the bark. In a preliminary study, chemical content data were obtained from untreated bark and from bark pretreated with a mild alkali solution to remove the suberin. The results indicated that the suberin did not hinder the chemical determinations. Hence, pretreatment of the bark with a mild alkali solution was not used for the bark and wood/bark chemical content determinations.

Analysis of variance was used to determine if significant differences existed within a clone by age and among clones at a given age for the wood, bark, and

TABLE 7. *Summary of lignin content for seven hybrid poplar clones by age and component.*

Age (yr)	Lignin content (% ovendry component weight)*						
	350	252	279	245	302	388	49
				Wood			
1	21.45	21.79	23.81	20.78	18.76	18.14	20.99
2	23.14	18.49	22.87	21.20	17.54	18.31	17.42
3	24.52A	17.36B	24.09A	21.69A	16.38B	17.45B	17.30B
4	25.58A	17.16B	23.04A	18.37B	16.62B	17.29B	18.83B
5	21.61A	19.94ABC	22.15AB	19.81ABC	17.58C	18.42BC	16.23C
6	25.70	20.53	19.63	21.37	19.69	17.26	17.88
7	22.87	18.08	18.67	17.38	17.06	16.37	19.63
8	21.85	17.53	20.39	17.05	18.85	17.96	17.21
				Wood/bark			
1	30.42A	25.47B	25.58B	25.64B	25.77B	21.27B	23.73B
2	28.42A	21.77C	26.39AB	23.66BC	29.18A	19.86C	21.35C
3	29.14A	22.69CD	24.00BC	21.13CD	26.44AB	20.15D	21.12CD
4	28.26A	20.24D	24.52BC	22.61CD	26.28AB	19.87D	21.86CD
5	30.29A	23.32B	22.25B	21.36B	28.32A	21.66B	21.21B
6	28.09AB	20.73C	23.15BC	20.92C	30.78A	22.51C	20.24C
7	27.45	20.47	25.66	20.08	29.77	21.16	21.08
8	29.29	23.93	22.41	22.90	26.62	18.38	20.37
				Bark			
1	30.43Cd	29.57C	38.60A	35.20B	31.30Cabc	31.07C	34.67B
2	36.72a	32.10	34.81	32.85	34.35a	30.43	36.12
3	34.25Aabc	32.96AB	37.43A	35.81A	33.37ABa	29.45B	34.03A
4	30.93cd	30.58	36.83	33.87	31.78ab	32.91	30.43
5	36.90Aa	30.39C	38.28A	35.27AB	31.87BCab	32.78BC	32.52BC
6	30.19d	29.56	36.95	34.29	32.13ab	33.65	33.55
7	32.20BCbcd	31.21BC	38.67A	36.51AB	29.82Cbc	34.07ABC	32.37BC
8	35.01Bab	30.74CD	38.84A	38.33A	28.02Dc	30.61CD	32.51BC

* Lignin content values are an average of 3 replications. Means with the same letter (lower case—among ages within a tissue and clone; upper case—among clones for a given age) are not significantly different at the 0.05 level.

wood/bark measured variables. Significant differences were established at the 0.05 level. Duncan's multiple-range test was used to separate significant treatment means.

RESULTS AND DISCUSSION

Comparing summaries of the heat of combustion (Table 3), extractive content (Table 4), holocellulose content (Table 5), alpha-cellulose content (Table 6), lignin content (Table 7), and ash content (Table 8) values for wood, bark, and wood/bark specimens from each clone at each age indicated: 1) wood had the highest holocellulose and alpha-cellulose content; 2) bark had the highest heat of combustion, extractive, lignin, and ash contents; and 3) combined wood/bark fuel and chemical content values were usually between the individual values for wood and bark. Significant differences were evident within and among clones and these statistical differences are indicated in Tables 3–8.

Heat of combustion values (Table 3) within a clone were significantly different for some of the wood (NE-279), bark (NE-49, NE-245, NE-302, and NE-350), and wood/bark (NE-49) specimens. However, no apparent trends with age were

TABLE 8. *Summary of ash content for seven hybrid poplar clones by age and component.*

Age (yr)	Ash content (% ovendry component weight)*						
	350	252	279	245	302	388	49
	Wood						
1	1.38BCa	1.28Da	1.44Ba	1.53Aa	1.25Da	1.10Ea	1.36Ca
2	1.24Ac	0.71Ede	1.20ABc	1.06Cb	1.19Bb	1.08Ca	0.79Dc
3	1.15Ad	0.85Cb	1.16Acd	0.98Bc	1.20Ab	0.88Cb	0.74Dd
4	1.08Be	0.62Ef	1.15Acd	0.87Cd	1.12Ac	0.88Cb	0.79Dc
5	1.33Ab	0.74Dcd	1.03Bf	0.85Cd	1.03Bd	0.86Cbc	0.66Ee
6	1.06Be	0.76CDc	1.09ABe	0.72DEe	1.13Ac	0.79Ccd	0.68Ee
7	0.97Cf	0.67Ee	1.14Ad	0.86Dd	1.03Bd	0.87Db	0.70Ede
8	1.05Be	0.82Db	1.27Ab	0.88Cd	0.90Ce	0.76Ed	0.87Cb
	Wood/bark						
1	2.82ABa	2.65BCa	2.89Aa	2.79ABCa	2.62Ca	2.41Db	2.39Da
2	1.91Cb	2.18Bb	2.11Bb	1.69Dc	1.81CDb	2.63Aa	1.42Ec
3	1.53Bc	2.09Ab	2.07Ab	1.50BCd	1.61Bc	2.20Ac	1.38Cc
4	1.57Cc	2.12Ab	2.05Ab	1.42Cde	1.85Bb	2.16Ac	1.22De
5	1.55CDc	1.64BCc	1.84Acd	1.44Dde	1.83Ab	1.77ABd	1.14Ef
6	1.59Bc	1.66Bc	1.90Ac	1.37Ce	1.87Ab	1.82Ad	1.28Dd
7	1.64Cc	1.43Dd	1.77Bd	1.24Ef	1.98Ab	1.62Cd	1.16Ff
8	1.82Bb	1.57Ccd	2.03Ab	1.82Bb	1.99Ab	1.83Bd	1.54Cb
	Bark						
1	5.33BCe	5.24Cd	4.85Df	4.92Dd	3.42Eef	5.96Af	5.37Bd
2	5.87Bc	5.30Cd	5.00De	4.97Dcd	3.25Ef	6.52Ae	5.38Cd
3	6.10Bb	5.67Dc	5.21Ecd	4.65Fe	3.58Ge	7.24Ab	5.74Cb
4	5.88Bc	5.62Cc	5.18Dd	5.02Ec	4.49Fd	7.00Ac	5.84Bb
5	5.92Cc	6.15Ba	5.24Ec	4.99Fcd	4.61Gd	7.29Ab	5.49Dc
6	5.72Cd	5.88Bb	5.33Db	4.67Fe	5.72Cc	6.79Ad	5.18Ee
7	5.94Cc	5.75Dbc	5.25Ec	5.19Eb	6.13Bb	6.97Ac	5.22Ee
8	6.84Ca	6.02Ga	6.15Fa	6.30Ea	7.28Ba	7.48Aa	6.42Da

* Ash content values are an average of 3 replications. Means with the same letter (lower case—among ages within a tissue and clone; upper case—among clones for a given age) are not significantly different at the 0.05 level.

evident in these clones. Close examination of the mean values within a clone and tissue in Table 1 revealed that the range in values was less than 350 cal/g. Comparisons among clones indicated that wood (6 years old), bark (1, 2, and 4 to 6 years old), and wood/bark (2 and 8 years old) heat of combustion values were significantly different, but parentage or clonal trends were not apparent. The range in heat of combustion values for the significant ages were less than 290 cal/g for wood, 450 cal/g for bark, and 400 cal/g for wood/bark. While statistical analyses indicated that some comparisons within and among clones were significant, the ranges in heat of combustion values were small with no apparent parentage trends in the data. Use of an average heat of combustion value within and among clones would suffice for practical use of heat of combustion values in estimating conversion potential for these clones.

Extractive contents by age (Table 4) within a clone were significantly different for wood (all clones except NE-302), bark (NE-252 and NE-350), and wood/bark (all clones) specimens. As age increased, the extractive content of wood and wood/bark specimens decreased for all clones. Similarly, as age increased, the extractive content for bark specimens decreased (NE-350, NE-252, NE-279) or remained relatively constant (NE-245, NE-302, NE-388, and NE-49). Comparisons among clones indicated that wood (3 to 8 years old), bark (1, 2, and 4 to 8 years old), and wood/bark (1 to 8 years old) extractive contents were significantly different, but parentage trends were not apparent. Data (Table 4) indicated that extractive contents were significantly different within and among clones, and chemical conversion strategies using these clones will need to consider age and clone.

Holocellulose contents (Table 5) within a clone were significantly different for wood (NE-350, NE-302, NE-252, NE-245, and NE-279), bark (NE-49, NE-350, NE-388, and NE-279), and wood/bark (NE-49, NE-252, and NE-302) specimens. Trends associated with parentages were not evident. For some clones, as age increased the holocellulose content of wood (NE-350, NE-252, NE-279), bark (NE-350 and NE-279), wood/bark (all clones) increased. For the other clones, as age increased the holocellulose content for the wood and bark specimens decreased or remained relatively constant. Comparisons among clones indicated that wood (1 to 7 years old), bark (1, 5, 7, and 8 years old), and wood/bark (2 to 8 years old) holocellulose contents were significantly different, but parentage trends were not consistent. Hence, chemical conversion strategies will depend on age and clone.

Statistical analysis of the alpha-cellulose (Table 6) data was not performed because the values represent only one determination. The values in Table 6 should be used only as an indication of the alpha-cellulose content of the components. Alpha-cellulose contents for wood specimens were higher than bark specimens. Differences within and among clones appeared to be minor.

Lignin contents by age (Table 7) within a clone were significantly different for only some of the bark (NE-350 and NE-302) specimens. Parentage trends were masked by either parent being used in other clones that had no significant difference within that clone. Lignin contents of bark were higher than wood. Comparisons among clones indicated that wood (3 to 5 years old), bark (1, 3, 5, 7, and 8 years old), and wood/bark (1 to 6 years old) lignin contents were significantly different. Hence, chemical conversion strategies will need to consider only the higher lignin content in the bark.

Ash contents for tissue (Table 8) within a clone and among clones by age were significantly different for wood, bark, and wood/bark specimens. As age increased, ash contents for bark specimens increased. Ash contents for wood and wood/bark specimens decreased with increasing age. The amount of bark influenced the ash content of the wood/bark specimens, because the ash contents of bark were more than four times the ash contents of wood.

Ash contains the inorganic elements in the biomass that are important macronutrients to the trees. Biomass production strategies will need to consider both the removal of these macronutrients and their replenishment on the site.

There were no statistical comparisons among wood, bark, and wood/bark values by clone for the properties examined in this study. However, the differences between wood and bark specimens were evident. Wood was higher in holocellulose and alpha-cellulose content than bark. Bark had higher heat of combustion, ash, lignin, and extractive content values than wood. The composite wood/bark chemical values were usually between the wood and bark values. Average chemical content values obtained in this study were similar to previously reported values (Bowersox et al. 1979; Murphey et al. 1979).

Analysis of the data from the seven clones indicates that the fuel and chemical contents depend more on whether the values are from wood, bark, or wood/bark specimens and age than clone. Extractive, holocellulose, and ash contents depend significantly on age within and among clones. The amount of bark present in the wood/bark specimens may have influenced some of the levels of significance for the chemical contents and particularly the gross heat of combustion values. Depending on the conversion strategy, the fuel and chemical content values as a function of age and clone may influence harvesting decisions for short-rotation *Populus* hybrids.

It appeared that the chemical properties of biomass produced from intensive culture of a dense *Populus* plantation can vary with tissue, tissue age, and parentage. The values for the wood and bark specimens produced the greatest differences among the measured properties. Tissue age appeared to be the second most important factor followed by parentage.

The results of these analyses demonstrated that tissue composition, tissue age, and parentage can influence selected properties. Some of the significant differences evident in the fuel and chemical values may moderate with increasing age or after combination with biomass yields. Researchers experimenting with intensive culture short-rotation biomass plantations should be aware of this variability when projecting the fuel and chemical potential and processing parameters of these systems.

A pattern for the parentage effects on the fuel and chemical content values between components and ages was not clear for the seven clones investigated. These results suggested that for the seven clones included in this study parentage had little effect on the chemical content values.

SUMMARY

The objective of this study was to add to the understanding of the conversion potential of short-rotation intensive culture biomass. Specifically, the study was designed to determine the fuel and chemical content values for seven *Populus* clones by component (wood, bark, and wood/bark specimens) and tissue age (1 to 8 years old). The specimens were evaluated for fuel (gross heat of combustion) and chemical content values (extractives, holocellulose, alpha-cellulose, lignin, and ash).

For the tissues tested: 1) wood was higher in holocellulose and alpha-cellulose content than bark; 2) bark was higher in gross heat of combustion, lignin, extractive, and ash content than wood; and 3) wood/bark composite fuel and chemical content values were usually between the values for wood and bark.

Evaluations of the wood, bark, and wood/bark tissues indicate that the tissue and tissue age influence the fuel and chemical values of biomass produced in short-rotations. Some of these differences may moderate with increasing age or after the fuel and chemical values are coupled with actual biomass yields. The significance of some properties may have no practical importance.

The results of this study demonstrate that harvesting decisions can influence the selected chemical properties of biomass produced in short-rotation intensively cultured *Populus* plantations. The variability in the fuel and chemical content values associated with tissue component, age, and parentage will influence the chemical yield and processing parameters of the biomass. In addition, researchers

evaluating these production systems should include these factors in their evaluation process.

REFERENCES

American Society for Testing and Materials. 1980a. Gross calorific value of solid fuel by adiabatic bomb calorimeter. Part 26, ASTM D 2015-66. Philadelphia, PA.

———. 1980b. Part 22. Standard test method for ash in wood. ASTM D 1102-78. Standard test method for alpha-cellulose in wood. Part 22, ASTM D 1103-77. Standard method for preparation of extractive-free wood. ASTM D 1105-79. Standard test method for lignin in wood. ASTM D 1106-77. Philadelphia, PA.

Anderson, H. W., and L. Zsuffa. 1975. Yield and wood quality of hybrid cottonwood grown in two-year rotation. Ontario Min. of Nat. Res., Forestry Research Report No. 101. 35 pp.

Bendtsen, B. A. 1978. Properties of wood from improved and intensively managed trees. For. Prod. J. 28(10):61–72.

———, R. R. Maeglin, and F. Deneke. 1981. Comparison of mechanical and anatomical properties of eastern cottonwood and *Populus* hybrid NE-237. Wood Sci. 14(1):1–14.

Bowersox, T. W., P. R. Blankenhorn, and W. K. Murphey. 1979. Heat of combustion, ash content, nutrient content, and chemical content of *Populus* hybrids. Wood Sci. 11(4):257–262.

Browning, B. L. 1967. Methods of wood chemistry. John Wiley & Son, Interscience Publ., Inc., New York, NY. 882 pp.

Cech, M. Y., R. W. Kennedy, and J. H. G. Smith. 1960. Variation in some wood quality attributes of one-year-old black cottonwood. Tappi 43(10):857–858.

Cheng, W. W., and D. W. Bensend. 1979. Anatomical properties of selected *Populus* clones grown under intensive culture. Wood Sci. 11(3):182–187.

Dawson, D. H., J. G. Isebrands, and J. C. Gordon. 1976. Growth, dry weight yields, and specific gravity of 3-year-old *Populus* grown under intensive culture. USDA Forest Serv. Res. Paper. NC-122. 7 pp.

Geyer, W. A. 1981. Growth, yield, and woody biomass characteristics of seven short-rotation hardwoods. Wood Sci. 13(4):209–215.

Hinish, W. W., M. R. Heddleson, and J. H. Eakin, Jr. 1967. Soil testing handbook. College of Agriculture, The Pennsylvania State University. 30 pp.

Holt, D. H., and W. K. Murphey. 1978. Properties of hybrid poplar juvenile wood affected by silvicultural treatments. Wood Sci. 10(4):198–203.

Hunt, K., and J. K. Keays. 1973. Short-rotation trembling aspen trees (*Populus tremuloides* Mich. ×) for kraft pulp. Can. J. For. Res. 3:180–184.

Laundrie, J. F., and J. G. Berbee. 1972. High yields of kraft pulp from rapid-growth hybrid poplar trees. USDA Forest Serv. Res. Rep. No. FPL-186. 24 pp.

Marton, R., G. Stairs, and E. J. Schreiner. 1968. Influence of growth rate and clonal effects on wood anatomy and pulping properties of hybrid poplars. Tappi 52(5):230–235.

Murphey, W. K., T. W. Bowersox, and P. R. Blankenhorn. 1979. Selected wood properties of young *Populus* hybrids. Wood Sci. 11(4):263–267.