EFFECTS OF ROTATION, SITE, AND CLONE ON THE CHEMICAL COMPOSITION OF *POPULUS* HYBRIDS[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

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ABSTRACT

Chemical content values were determined for three *Populus* clones grown on two dissimilar sites by component (wood, bark, and wood/bark specimens), tissue age (1-, 2- and 4-years-old), and rotation. The chemical content values obtained included extractives, holocellulose, alpha-cellulose, and lignin. In general, analysis of the data for the wood, bark, and wood/bark specimens indicated that: 1) wood was high in holocellulose and alpha-cellulose content compared to bark, 2) bark was high in lignin and extractive content values compared to wood, and 3) wood/bark chemical content values were between the values for the wood and bark specimens.

The chemical content data were analyzed to identify: 1) significant differences between rotations by component (wood, bark, and wood/bark) for a given age, clone, and site, and 2) significant differences between sites for four-year-old wood, bark and wood/bark specimens of a given rotation, and clone. Statistical analyses indicated that significant differences existed among clones, sites, ages, and rotations. Within the wood, bark and wood/bark specimens, tissue age, rotation, and site influenced the chemical content values more than the parentage. Potential chemical yields derived from the three *Populus* hybrid clones investigated will depend on component, age, rotation, and site with limited parentage effects.

Keywords: *Populus* hybrids, site, clones.

INTRODUCTION

Biomass from intensively managed plantations is being considered as a future source of chemicals. Utilization of short-rotation forest biomass as a chemical source will depend on the chemical properties such as 1) extractive content, 2) holocellulose content, 3) lignin content, and 4) alpha-cellulose content. Data on the utilization, particularly pulping characteristics, of short-rotation forest biomass are beginning to appear in the literature (Anderson and Zsuffa 1975; Bendtsen 1978; Bendtsen 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; and Murphey et al. 1979). These studies provide needed information for 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 will differ, to some extent, from the traditional harvesting

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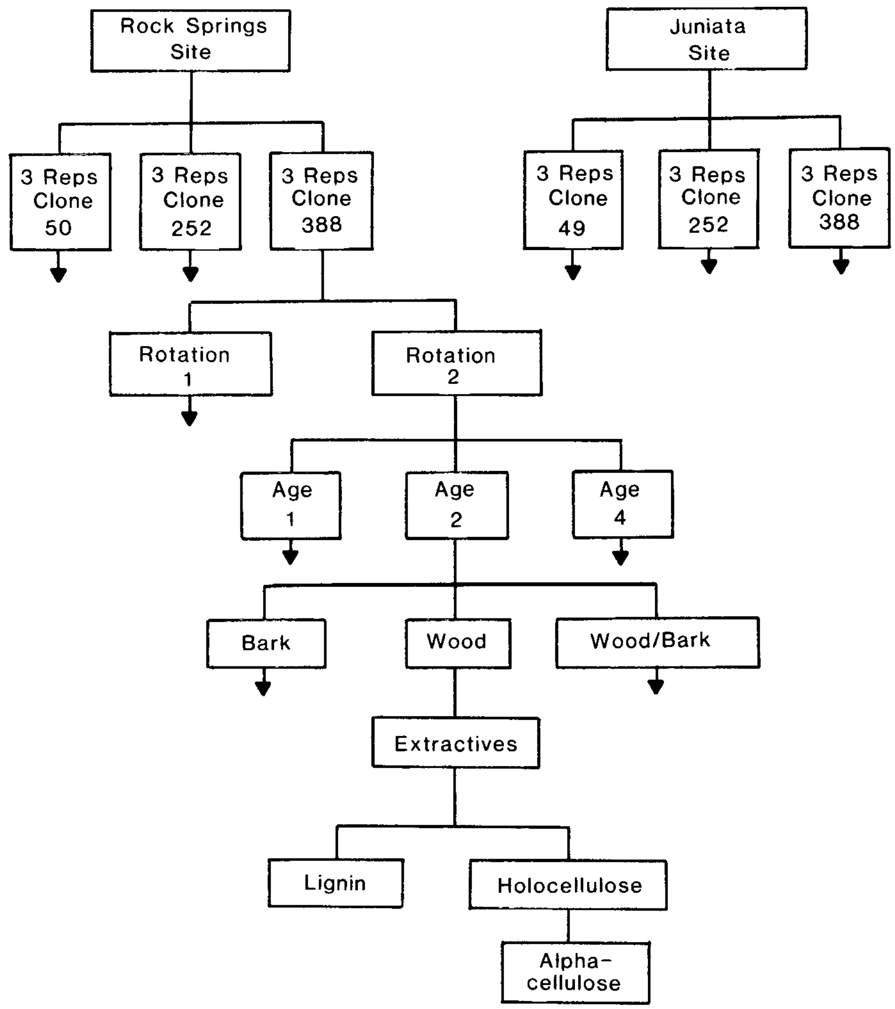

FIG. 1. Experimental design for determining the effects of rotation, site and clone on the chemical composition of *Populus* hybrids.

and processing techniques. One advantage in processing short-rotation forest biomass is the uniform properties in a given clone. An understanding of the variation in the chemical properties among clones, within a clone (by tissue age), between rotations and between sites will aid in genetic selection, silvicultural management, and establishing basic data needed to utilize this forest biomass as a source of chemicals.

The objective of the study was to determine the variation in chemical values due to site, parentage, and rotation of the biomass produced in dense plantations of *Populus* hybrids. Wood, bark, and wood/bark specimens representing 1-, 2- and 4-year-old biomass from first and second rotations of three clones growing on two sites were collected, and the chemical composition (total extractives, holocellulose, alpha-cellulose and lignin) was determined.

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

Clone	Parentage	
	Female	Male
NE-49 or -50	*maximowiczii*	'Berolinensis'
NE-252	'Angulata'	*trichocarpa*
NE-388	*maximowiczii*	*trichocarpa*

PROCEDURES

A generalized flow diagram for obtaining the chemical content values for three *Populus* clones is presented in Fig. 1, and parentages for the three clones are presented in Table 1. Clones NE-49 and -50 are crosses between a balsam poplar of Japan and 'Berolinensis' (a cross between a balsam poplar (*laurifolia*) and a black poplar (*nigra*)). Clone NE-252 is a cross between 'Angulata' (a cultivar from the subspecies *P. deltoides angulata* (a black poplar)) and a balsam poplar, and Clone NE-388 is a cross between two balsam poplars.

Specimens representing the first rotation at the Juniata site were selected from four-year-old tissue and second rotation selections were made from the four-year-old coppice. Specimens from the Rock Spring site were collected from side-by-side four-year-old plantations in their first and second (coppice) rotations.

The Juniata site was marginal for row crops and typified abandoned farmland with soil that was shallow and low in inherent fertility and water holding capacity. It was derived from gray brown acid thin-bedded shale (*Lithic Dystrochrept: loamy-skeletal, mixed, mesic*). The Rock Springs site was considered to be good to excellent for row crops in that the soil was deep and inherently high in fertility and water holding capacity. It was derived from relatively pure limestone (*Typic Hapludult, clayey, mixed, mesic*). Both sites were located in the Ridge and Valley Physiographic Region of central Pennsylvania.

Wood, bark, and wood/bark specimens by site, age, and rotation for each clone were separated from the trees. The one-year-old tissues were collected from terminal growth produced in the last growing season of the rotation. The two-year-old tissues were a combination of one- and two-year-old tissues, and the four-year-old tissues were a combination of 1- to 4-year-old tissues.

Chemical values for the replicated clones by site, rotation, age, and component were obtained using the following test procedures: 1) extractive content—ASTM D1105-79, 2) lignin content—ASTM D1106-77, 3) holocellulose content (Browning 1967), and 4) alpha-cellulose content—ASTM D1103-77. The standards were applied to smaller sized specimens than recommended because of the limited

TABLE 2. *Average values for the selected properties of wood, bark, and wood/bark specimens from two sites, two rotations, three tissue ages, and three clones. Units are on an oven-dry weight basis.*

	Wood	Bark	Wood/bark
Extractives	9.9%	35.1%	15.8%
Lignin	18.6%	20.6%	19.3%
Holocellulose	72.4%	44.9%	65.7%
Alpha-cellulose	43.7%	39.2%	42.3%

TABLE 3. *Summary of the average extractive content values for three* Populus *hybrid clones from the Rock Springs and Juniata Plantations.*[1]

Specimen		Extractives (%)[2]					
		Rock Springs			Juniata		
		Wood	Bark	Wood/bark	Wood	Bark	Wood/bark
Clone 49-50							
Rotation 1	1 yr	13.2a	35.2a	21.2a	7.2a	23.4a	13.4a
	2 yr	7.5b	27.3b	12.0b	7.4b	27.9b	10.6b
	4 yr	6.7cCD	35.0cAC	7.9cAD	7.2CD	27.4cAC	9.6cAD
Rotation 2	1 yr	14.1a	34.4a	23.8a	16.5a	33.3a	25.8a
	2 yr	10.2b	34.8b	15.4b	10.4b	36.7b	20.3b
	4 yr	7.7cBCD	40.6cBC	8.3cBD	7.1BCD	33.5cBC	10.7cBD
Clone 252							
Rotation 1	1 yr	14.6a	35.5a	25.3a	9.0a	29.3a	15.5a
	2 yr	8.8b	38.0b	12.0b	8.4b	25.9b	16.0b
	4 yr	5.8cACD	34.8cAC	7.6cAD	6.8cACD	28.2cAC	11.8cAD
Rotation 2	1 yr	16.7a	32.7a	23.5a	18.1a	35.5a	26.8a
	2 yr	10.5b	35.7b	17.0b	12.4b	40.7b	20.1b
	4 yr	6.4cBCD	36.1cBC	8.8cBD	7.9cBCD	38.5cBC	13.1cBD
Clone 388							
Rotation 1	1 yr	11.9	36.5	20.0a	9.9a	30.5a	14.5a
	2 yr	8.3	39.9	13.3b	8.8b	31.0b	12.0b
	4 yr	5.5ACD	39.1AC	9.5AD	7.5cACD	32.1cAC	10.9cAD
Rotation 2	1 yr	13.4	39.3	24.5a	16.3a	37.9a	28.4a
	2 yr	9.8	37.9	16.0b	11.3b	40.9b	20.9b
	4 yr	7.3BCD	46.8BC	9.9BD	7.8cBCD	39.2cBC	11.7cBD

[1] A small letter (a—1 yr, b—2 yr, c—4 yr) indicates a significant difference between rotations for each age within a clone and site. A capital letter (A—first rotation and B—second rotation) indicates a significant difference between sites for four-year-old material from a given rotation associated with each clone. A capital letter (C—wood versus bark and D—wood versus wood/bark) indicates a significant difference between four-year-old material from a given rotation associated with each clone and site.
[2] Values are in percent of oven-dry weight and are an average of six specimens.

amount of younger material, but the specimen size was the same for all ages. This permitted relative comparisons among clones, site, age, and rotation treatments.

Chemical analysis of bark may be difficult because of the suberin and other waxlike substances in the bark. In a preliminary study, chemical content data were obtained for untreated bark and bark pretreated with a mild alkali solution used to remove the suberin. The results of this study 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 among the variables investigated. Statistical differences were established at the 0.05 level of significance.

RESULTS AND DISCUSSION

The results of the tests indicated that the properties of biomass produced from intensive culture of a dense *Populus* plantation can vary with site, rotation, tissue, tissue age, and parentage. Relative amounts of wood and bark in the specimens

TABLE 4. *Summary of the average lignin content values for three* Populus *hybrid clones from the Rock Springs and Juniata Plantations.*[1]

Specimen		Lignin (%)[2] Rock Springs Wood	Rock Springs Bark	Rock Springs Wood/bark	Juniata Wood	Juniata Bark	Juniata Wood/bark
Clone 49-50							
Rotation 1	1 yr	20.5a	19.1	21.5a	19.5	26.6a	20.6a
	2 yr	20.4	18.7	20.2	16.1	26.0b	19.1b
	4 yr	16.2	21.1c	18.5c	17.5CD	22.1cC	19.8D
Rotation 2	1 yr	19.5a	18.4	19.8a	20.4	22.7a	23.7a
	2 yr	18.7	17.8	20.1	17.4	19.1b	20.4b
	4 yr	17.9C	13.5cBC	14.0c	18.0CD	25.3cBC	17.8BD
Clone 252							
Rotation 1	1 yr	18.8	18.2a	21.3	19.8	20.9	21.5
	2 yr	18.2	19.9b	19.9	18.8b	23.8b	18.3
	4 yr	16.8CD	25.0AC	18.1D	16.2cC	22.0cAC	17.9
Rotation 2	1 yr	19.8	23.1a	22.1	21.9	20.9	23.7
	2 yr	21.0	21.8b	19.4	22.0b	16.0b	16.4
	4 yr	18.5C	24.7BC	17.4	15.0c	20.0cB	15.6
Clone 388							
Rotation 1	1 yr	22.0	17.9	22.3a	16.3a	21.6	18.2
	2 yr	23.2	17.1	20.2	16.7	21.0	17.5
	4 yr	16.7C	18.2cC	16.9	17.5C	22.3C	17.7
Rotation 2	1 yr	17.9	17.8	19.6a	22.2a	21.5	21.8
	2 yr	18.8	17.9	19.8	18.2	18.6	19.8
	4 yr	16.6D	19.4cB	19.9D	15.5	20.6B	18.2

[1] A small letter (a—1 yr, b—2 yr, c—4 yr) indicates a significant difference between rotations for each age within a clone and site. A capital letter (A—first rotation and B—second rotation) indicates a significant difference between sites for four-year-old material from a given rotation associated with each clone. A capital letter (C—wood versus bark and D—wood versus wood/bark) indicates a significant difference between four-year-old material from a given rotation associated with each clone and site.

[2] Values are in percent of oven-dry weight and are an average of three specimens.

produced the greatest variability among the measured properties. Tissue and tissue age appeared to be important factors followed by—and in descending order of importance—rotation, site, and parentage. Consistent trends associated with parentages were not evident.

Average chemical values for wood, bark, and wood/bark specimens for the three *Populus* clones grown on two sites are presented in Table 2. These values may be useful in comparing the properties of biomass produced in intensive culture of dense plantations with products from more traditional forest biomass systems.

Statistical comparisons between wood-bark and wood-wood/bark chemical values for four-year-old material in each clone at both sites for two rotations indicated that the extractive and holocellulose content values were significantly different, except for Clone 252 wood-wood/bark holocellulose values from the Rock Springs site. Additional analyses were conducted (Tables 3–6). In general, wood was higher in holocellulose and alpha-cellulose content than bark, bark had higher extractive and lignin content values than wood, and the composite wood/bark chemical values were between the wood and bark values. Average chemical content values obtained in this study were similar to previously reported values (Bowersox et al. 1979 and Murphey et al. 1979).

TABLE 5. *Summary of the average holocellulose content values for three* Populus *hybrid clones from the Rock Springs and Juniata Plantations.*[1]

Specimen		Holocellulose (%)[2] Rock Springs Wood	Rock Springs Bark	Rock Springs Wood/bark	Juniata Wood	Juniata Bark	Juniata Wood/bark
Clone 49-50							
Rotation 1	1 yr	71.4	50.6	63.9a	71.6a	39.4a	52.8a
	2 yr	75.1	49.0b	71.6	73.0	41.4	60.6
	4 yr	79.8ACD	51.9cC	77.6AD	73.2cACD	51.4C	69.2cAD
Rotation 2	1 yr	71.2	51.4	59.7a	64.8a	50.3a	57.6a
	2 yr	73.7	52.5b	68.3	72.0	44.9	63.1
	4 yr	79.1BCD	47.0cBC	79.8BD	80.5cBCD	49.4BC	74.4cBD
Clone 252							
Rotation 1	1 yr	70.8a	49.6	59.6	60.0	33.3a	53.8
	2 yr	76.2b	49.3b	74.0b	64.6b	38.4b	48.4b
	4 yr	79.2AC	47.7AC	79.9A	67.6cACD	38.9cAC	56.7cAD
Rotation 2	1 yr	66.1a	49.8	58.8	63.9	47.4a	56.9
	2 yr	74.0b	46.9b	66.8b	69.4b	42.2b	62.2b
	4 yr	79.9BC	46.3C	79.1B	76.6cBCD	45.7cC	73.5cBD
Clone 388							
Rotation 1	1 yr	71.9	47.7a	65.4a	68.7	34.7a	60.3a
	2 yr	75.6	46.0	69.7	74.4b	33.0b	66.5b
	4 yr	80.9cACD	45.4cAC	78.1cAD	64.6cACD	32.6cAC	64.7cAD
Rotation 2	1 yr	70.2	43.5a	59.5a	65.1	46.2a	51.5a
	2 yr	74.1	46.9	67.8	72.0b	44.7b	61.4b
	4 yr	76.0cBCD	35.8cBC	75.1cD	80.9cBCD	45.6cBC	75.3cD

[1] A small letter (a—1 yr, b—2 yr, c—4 yr) indicates a significant difference between rotations for each age within a clone and site. A capital letter (A—first rotation and B—second rotation) indicates a significant difference between sites for four-year-old material from a given rotation associated with each clone. A capital letter (C—wood versus bark and D—wood versus wood/bark) indicates a significant difference between four-year-old material from a given rotation associated with each clone and site.
[2] Values are in percent of oven-dry weight and are an average of three specimens.

Rotations and tissue age

The chemical content data, summarized in Tables 3–6, were statistically analyzed to identify significant differences between rotations for a given age, clone, and site. These analyses identified age effects for the components (wood, bark, and wood/bark) between rotations within a clone and site.

Analyses of the extractive content data (Table 3) indicated that there were significant differences between rotations for the wood, bark, and wood/bark specimens for each clone (except the wood and bark specimens for Clone 388 from Rock Springs) harvested from the Rock Springs and Juniata sites. General trends in the extractive content values for the wood, bark, and wood/bark specimens from both sites included: 1) higher extractive content values associated with younger material, except for bark, 2) extractive content values were higher in the second rotation than the first rotation, 3) extractive contents were highest for bark and lowest for wood, and 4) bark extractive contents for the Rock Springs first rotation trees were higher than the Juniata Plantation first rotation trees.

For the most part, statistical analyses of the lignin content data (Table 4) indicated non-significance, particularly for the wood and wood/bark components, between rotations for a given age, clone, and site. In general, the lignin content

TABLE 6. *Summary of the average alpha-cellulose content values for three* Populus *hybrid clones from the Rock Springs and Juniata Plantations.*[1]

Specimen		Rock Springs Wood	Rock Springs Bark	Rock Springs Wood/bark	Juniata Wood	Juniata Bark	Juniata Wood/bark
		Alpha-cellulose (%)[2]					
Clone 49-50							
Rotation 1	1 yr	42.4a	43.3	42.5a	41.5a	28.3a	34.3
	2 yr	44.9b	43.7	44.9b	43.0b	29.8	39.1b
	4 yr	49.2cAC	44.0AC	47.8cA	41.3cACD	27.5cAC	39.4cAD
Rotation 2	1 yr	41.4a	43.4	45.1a	36.6a	40.4a	41.3
	2 yr	48.6b	44.1	49.0b	41.7b	38.0	41.3b
	4 yr	45.1cBC	42.7BC	43.5c	43.2cB	38.7cB	42.3c
Clone 252							
Rotation 1	1 yr	42.2	41.2	40.6	38.2a	28.8a	38.6
	2 yr	46.2b	42.6b	45.8	41.9b	30.3b	34.6
	4 yr	44.8cAC	37.6AC	48.1cA	40.8cACD	33.7cAC	37.7cAD
Rotation 2	1 yr	42.5	39.3	40.8	36.8a	40.8a	39.0
	2 yr	47.1b	38.6b	45.2	41.3b	39.0b	38.5
	4 yr	47.9cBCD	36.4BC	42.4cBD	43.4cB	39.7cB	43.7cB
Clone 388							
Rotation 1	1 yr	42.4a	39.3a	42.4	43.3a	31.3a	38.8
	2 yr	45.8b	39.6	44.6	45.1b	30.5b	39.7b
	4 yr	45.7cAC	43.5cAC	46.4A	42.2cACD	27.6cAC	40.3AD
Rotation 2	1 yr	43.7a	36.7a	42.3	38.8a	41.1a	34.9
	2 yr	45.5b	39.4	43.8	44.0b	40.7b	42.0b
	4 yr	47.2cBCD	33.6cBC	45.7D	44.8cBC	40.9cBC	45.1

[1] A small letter (a—1 yr, b—2 yr, c—4 yr) indicates a significant difference between rotations for each age within a clone and site. A capital letter (A—first rotation and B—second rotation) indicates a significant difference between sites for four-year-old material from a given rotation associated with each clone. A capital letter (C—wood versus bark and D—wood versus wood/bark) indicates a significant difference between four-year-old material from a given rotation associated with each clone and site.

[2] Values are in percent of extractive free oven-dry weight and are an average of three specimens for rotation 2. The value for rotation 1 is for a single specimen.

values decreased slightly for wood and wood/bark specimens with increasing age in a rotation for a given clone and site.

Trends in the holocellulose content data (Table 5) were less pronounced than trends in the extractive and lignin content data. The Juniata plantation had a larger number of significant differences between rotations at a given age than the Rock Springs plantation. This indicated a possible site influence on the holocellulose content. In general, the holocellulose content of the wood and wood/bark specimens increased with age for each rotation associated with each clone on both sites. In contrast, the bark holocellulose content increased with age for the Juniata plantation first rotation and remained fairly constant or decreased slightly for the Juniata plantation second rotation and the Rock Springs first and second rotation.

Analyses of the alpha-cellulose content data (Table 6) indicated that there were significant differences between rotations for bark, wood/bark and particularly wood specimens for each clone and site. In general, the alpha-cellulose content of the wood and wood/bark specimens increased with age for each rotation associated with each clone on both sites. The alpha-cellulose content values for bark remained the same or decreased slightly for each rotation, clone, and site.

In summary, it appears that tissue age and rotation influenced the chemical content values. However, the older age chemical component values appear to be somewhat similar within the wood, bark, and wood/bark specimens for the three clones in both rotations.

Sites

The chemical data summarized in Tables 3–6 were statistically analyzed to identify differences between sites for four-year-old components (wood, bark, and wood/bark) of a given rotation and clone. Four-year-old material was selected for the statistical analyses because this age class represents a probable rotation length for these *Populus* plantations. This approach provided additional information to the analyses evaluating differences between rotations.

Significant differences were found in the extractive content data (Table 3) between sites for the four-year-old wood, bark, and wood/bark specimens. General trends in the four-year-old extractive content values indicated that: 1) extractive contents for wood specimens in the first rotation were higher for the Juniata plantation than the Rock Springs plantation for each clone, 2) extractive contents for most of the wood specimens in the second rotation were somewhat higher for the Rock Springs plantation than the Juniata plantation, 3) extractive contents for most of the bark specimens were higher in the first and second rotation for the Rock Springs plantation, and 4) extractive contents for wood/bark specimens were higher in the first and second rotation for the Juniata plantation. These analyses implied that the site can influence extractive contents. Higher extractive contents for four-year-old wood and wood/bark specimens were associated with the slower growing trees at the Juniata site, while higher extractive contents for four-year-old bark specimens were associated with faster growing trees at the Rock Springs site.

Statistical analyses of the lignin content data (Table 4) for the four-year-old specimens indicated that most of the wood and wood/bark specimens for both rotations and the bark specimens from the first rotation were essentially the same between sites. In the second rotation, the lignin content of the bark was significantly different between sites. Lignin content values between sites for four-year-old material in each rotation were similar, which was consistent with the large amount of non-significant differences.

Holocellulose content data (Table 5) for the four-year-old wood, bark, and wood/bark specimens were significantly different between sites. The four-year-old specimens obtained from the Rock Springs plantation had substantially higher holocellulose content values for the first rotation than specimens obtained from the Juniata Plantation. In the second rotation, the majority of the holocellulose content values for the four-year-old specimens obtained from the two plantations were significantly different, but the range in the values had decreased compared to the range in first rotation values. This result suggested that significant differences between sites may diminish with subsequent rotations.

Alpha-cellulose content data (Table 6) for the four-year-old wood and bark specimens for both rotations and wood/bark specimens for the first rotation were significantly different. The alpha-cellulose content data for the four-year-old wood/bark specimens for the second rotation between sites were essentially not significantly different. Four-year-old specimens for both rotations from the Rock Springs plantation had higher alpha-cellulose content values than similar specimens obtained from the Juniata plantation, except the second rotation bark specimens. The better site appeared to produce more alpha-cellulose than the poorer site.

Parentage

A pattern for the parentage effects on the chemical content values between sites, ages, and rotations was not clear, and patterns that were evident appeared to be inconsistent for the three clones investigated. These results suggested that for the three clones included in this study parentage had little effect on the chemical content values.

SUMMARY

The biomass production potential of dense *Populus* plantations has been studied for more than a decade with limited data on the utilization characteristics. 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 chemical content values for three *Populus* clones grown on two sites by component (wood, bark, and wood/bark specimens), tissue age (1-, 2-, and 4-year-old), and rotation. The specimens were evaluated for chemical content values (extractives, holocellulose, alpha-cellulose, and lignin).

For the tissues tested: (1) wood was higher in holocellulose and alpha-cellulose content than bark, (2) bark was higher in lignin and extractive content than wood, and (3) wood/bark composite chemical content values were between the values for wood and bark.

Evaluations of the wood, bark, and wood/bark tissues indicate that the site, rotation, and tissue age significantly influence the chemical values of biomass produced in short rotations. Some of these differences may moderate with increasing age or after the 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 cultural and harvesting decisions can influence the selected chemical properties of biomass produced in short-rotation intensively cultured *Populus* plantations. Researchers evaluating these production systems should include these factors in their evaluation process. In addition, the variability in the chemical content values associated with rotation, site, tissue component, age, and parentage will influence the chemical yield and processing parameters of the biomass.

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