KRAFT PULP YIELDS AND PAPER PROPERTIES OBTAINED FROM FIRST AND SECOND ROTATIONS OF THREE HYBRID POPLAR CLONES[1]

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(Received 26 February 1982)

ABSTRACT

Studies indicate that short rotation intensive cultured (SRIC) *Populus* hybrid clones could be utilized as wood source for some paper grades. However, to take advantage of the SRIC system, acceptable pulp yields and paper properties must be obtained from subsequent tree rotations. Therefore, a study was undertaken to evaluate and compare the kraft pulp yields and paper properties obtained from first and second rotations of three *Populus* hybrid clones harvested at three years of age.

No significant differences ($P \leq 0.05$) in total kraft pulp yields were measured between first and second tree rotations, although slightly higher yields were consistently obtained from all three clones of second rotation trees. Comparisons of handsheet strength properties between rotations showed significant improvements in handsheet tensile properties for clones 50 and 252 and handsheet tear for clone 252. Strength improvements for these clones may, in part, be attributed to improved fiber characteristics obtained from sprouts regenerated from stumps as opposed to vegetative propagation.

Difficulties in paper machine operation can possibly be encountered because of the preponderance of fines and debris found in both first and second rotation of juvenile *Populus* hybrid total tree pulp. Initially, low freeness levels (CSf) with minimal refining indicate that some adjustments for paper machine operation may be necessary to accommodate this type of pulp in the furnish.

Keywords: Kraft, paper properties, poplar.

INTRODUCTION

Utilization of short rotation, fast-growing hardwoods as a wood supply for the paper industry has aroused a considerable amount of interest during the past decade (Barker 1974; Einspahr et al. 1970, 1979; Isebrands and Parham 1974). Studies have also suggested that short rotation intensive culture

[1] This paper was presented in part at the 35th Annual Meeting of the Forest Products Research Society, June 1981, in St. Paul, Minnesota. This study was supported by State McIntire-Stennis funds and has been approved as Journal Series No. 6351. The authors wish to thank Westvaco Corporation for the use of the Tyrone mill paper testing lab.

(SRIC) plantations offer potentially greater chip yields per acre and some economic advantages over current wood fiber production methods (Zavitkovski and Dawson 1978).

Populus hybrids from SRIC systems were demonstrated to have potential use as a wood source for some paper grades (Marton et al. 1968; Zarges et al. 1980). In order to take advantage of this system of growing trees, acceptable pulp yields and paper properties must be obtained from subsequent tree rotations. To date, investigators have reported only on pulp and paper quality obtained from first rotations. This paper compares and reports on the kraft pulp yields and three selected paper properties obtained from first and second rotations (rotation from cuttings compared to stump sprouts for second rotation) of three *Populus* hybrids grown on the same site and harvested at 3 years of age.

MATERIALS AND METHODS

Raw materials

In 1972 a plantation of three *Populus* hybrids was established in central Pennsylvania using the clones NE-50 (*Populus maximowiczii* × cultivar 'Berolinensis'), NE-252 (*P.* cultivar 'Angulata' × *trichocarpa*), and NE-388 (*P. maximowiczii* × *trichocarpa*). The 1972 plantation was harvested in the 1976–1977 dormant season, and the stump sprouts formed at the beginning of the 1977 growing season started the second rotation. A second plantation of the same parentage was planted as cuttings in 1977. Both of the plantations were planted in a Hagerstown silt loam, adjacent to each other and at 1 tree per 5.0 ft^2. All trees were harvested just before leaf emergence in the spring of 1980.

Total tree chips were randomly collected from each plantation during harvest. Because the chipper used did not produce a quality chip, a considerable amount of hand preparation was involved. Oversized chips, particularly stems and branches, were cut and reduced to acceptable size. Average chip sizes used in this study were approximately ½ × ¾ × ⅛ inch thick. No attempt was made to remove all the bark residue. The hand-sorted chips were washed and screened to remove debris, and fines were discarded. Chips were stored in polyethylene bags in a cold room at −5 C prior to pulping studies.

Pulping

Kraft pulps were prepared in a 2-liter M/K System laboratory digester. Prior to pulping studies on the six wood samples (3 parentages and 2 rotations), preliminary cooks were made to ascertain the cooking conditions to be used in this study. These initial digestion trials were conducted to evaluate the type of pulp obtained, since screening facilities were not available in this laboratory to remove shives from the pulp. The digested chips were washed with water and then passed through a Bauer disk refiner to enhance fiber separation and pulp washing. The washed pulp was placed in a screened box to drain; the pulp was hand-squeezed and sampled for moisture content; and total pulp yield determinations were made. TAPPI standard T214m-50 was used to measure the permanganate number of the pulp.

Duplicate kraft cooks were made on each wood source, and the pulping conditions used in the experiment are summarized in Table 1. Each pulping condition

TABLE 1. *Kraft pulping conditions used in the M/K mini-mill digester.*

	Trial 1	Trial 2
Minutes to temperature	60	60
Minutes at temperature	120	120
Maximum temperature (°C)	173	173
Chip charge (g)	400	400
Effective alkali (%)	15	13
Sulfidity (%)	25	25
Liquor to wood ratio	5:1	5:1
Minutes cool-down	30	30

was designated as trial 1 or 2. The experiment was a three-way factorial (clone × rotation × pulping condition) with replication. Data were analyzed using the three-way analyses of variance with replication procedures described in Steel and Torrie (1960).

Handsheet testing

Six soft[2] pulps were selected for handsheet evaluation studies from trial 1 (Table 2). Pulps obtained in trial 2 contained a large amount of shives, and it was felt that this condition would interfere and make it more difficult to evaluate paper strength results. Previous investigators have reported similar difficulties when evaluating handsheets made from total tree pulps (Zarges et al. 1980). For this reason, only pulps with a low permanganate number were selected.

A Bauer single-rotation disk refiner was used to refine the pulp, instead of a Valley beater. Work experience using different types of refiners indicates that a considerable amount of variation in paper strength can be achieved, depending on the condition and type of refiners used in pulp treatment. Therefore, we deviated from TAPPI procedures and evaluated disk-refined pulps. It was felt that this refining method would provide a better indication as to the potential paper strength development obtained from *Populus* wood pulp.

Canadian Standard freeness (CSf) was measured using deionized water for disk-refined pulps. Handsheets were made according to TAPPI standard T205os-71

[2] Soft pulp refers to pulps digested to a low permanganate number or low pulp residual lignin content.

TABLE 2. *Pulps selected for handsheet evaluation studies.*

Pulp	Permanganate no.	Total pulp yield (%)
Clone 388 (1st rotation)	9.8	49.2
Clone 388 (2nd rotation)	11.3	51.5
Clone 252 (1st rotation)	10.0	46.5
Clone 252 (2nd rotation)	10.9	48.2
Clone 50 (1st rotation)	8.9	48.3
Clone 50 (2nd rotation)	11.3	49.8

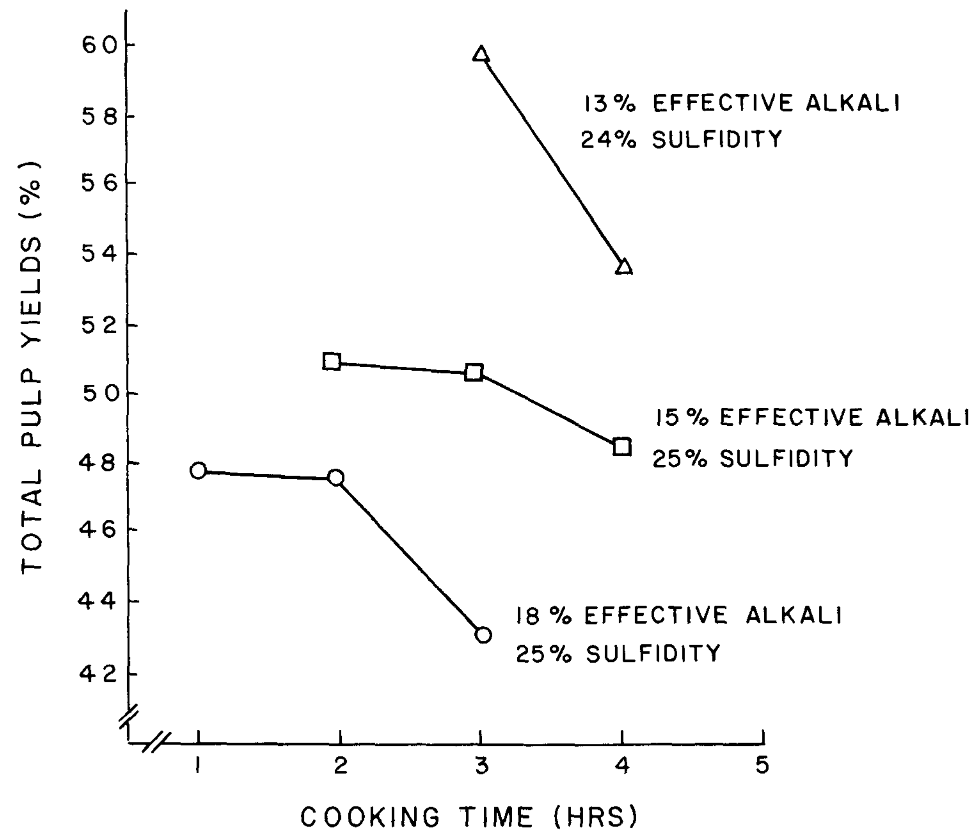

FIG. 1. Total pulp yields (%) obtained from mixed hybrid poplar chips cooked at various kraft schedules.

and tested according to Standard T220m-60. The handsheets were tested at Westvaco's Tyrone Papermill paper testing facilities for tensile and tear properties. A Tinus Olsen automatic horizontal tensile tester was used to measure tensile properties. Each of the handsheet strength properties was regressed against CSf for each rotation in each of the three clones, and predicted strength comparisons were determined for a constant freeness. Comparisons of the two regression lines (rotation one versus two) were analyzed using the procedures described in Neter and Wasserman (1974).

RESULTS AND DISCUSSION

Pulp yields

Preliminary kraft cooks were made at three active alkali concentrations on mixed total tree *Populus* chips, and the results are presented in Fig. 1. As expected, total pulp yields decreased with increasing alkali concentration and cooking time. Pulp yields ranged from a low of 43% to a high of 60%, depending on the kraft cooking procedures.

Comparison of the pulp yield results observed in this study with those reported

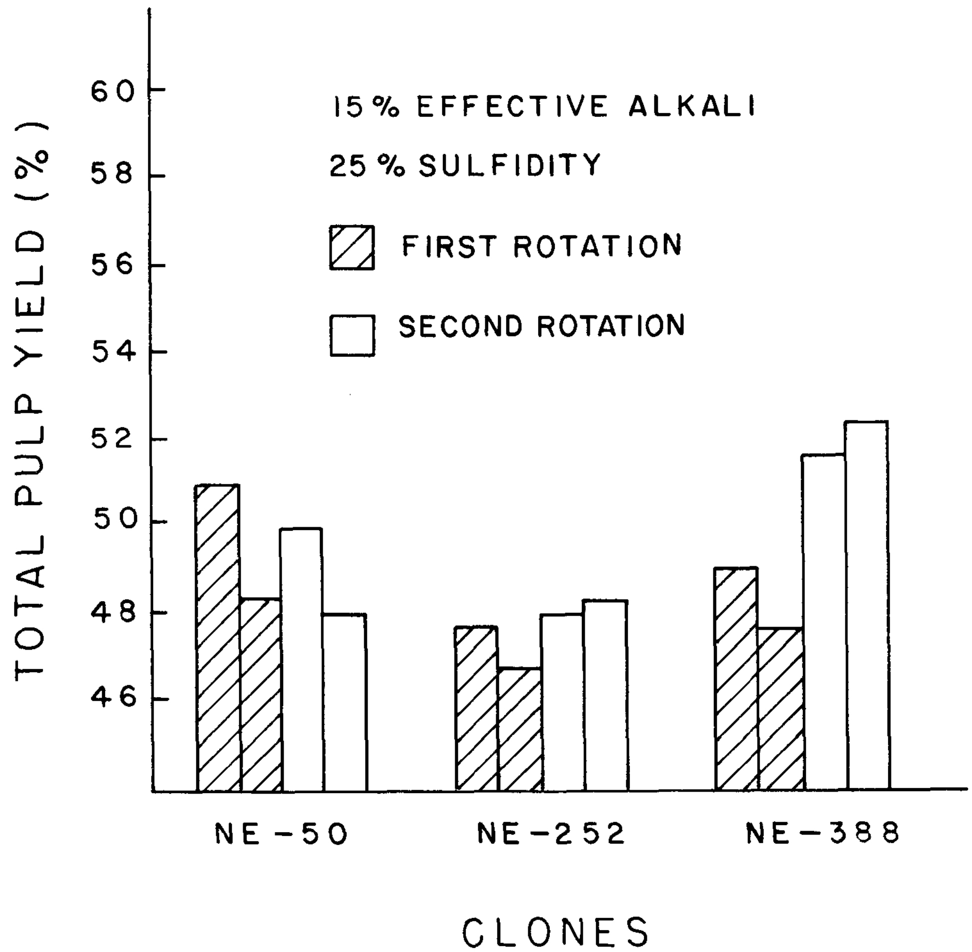

FIG. 2. Trial 1—Total pulp yields (%) of three *Populus* hybrids digested with 15% effective alkali.

in the literature indicates that under similar cooking conditions, pulp yields were somewhat lower than the yields reported. Marton and coworkers (1968) reported pulp yields of 51 to 52% for wood from 13- to 14-year-old traditionally spaced *Populus* trees kraft digested at 18% active alkali and 25% sulfidity. Zarges and coworkers (1980) reported screened pulp yields of 49 to 53% for 5- and 7-year-old total tree poplar plantations digested at 14 to 16% effective alkali range. In this study results were lower (43 to 51%), and these preliminary trials indicate and support Marton's finding that tree age may be a factor affecting kraft pulp yields.

Significant differences ($P \leq 0.05$) in total pulp yields were measured among the three *Populus* hybrids digested at the two cooking schedules (Figs. 2 and 3). Duplicate kraft cooks from each trial and clone are reported, and data show that higher average pulp yields were obtained from clone 388, followed by clones 50 and 252. Although a Duncans test was not performed, it appears that the differences between clones 50 and 252 may not be significant.

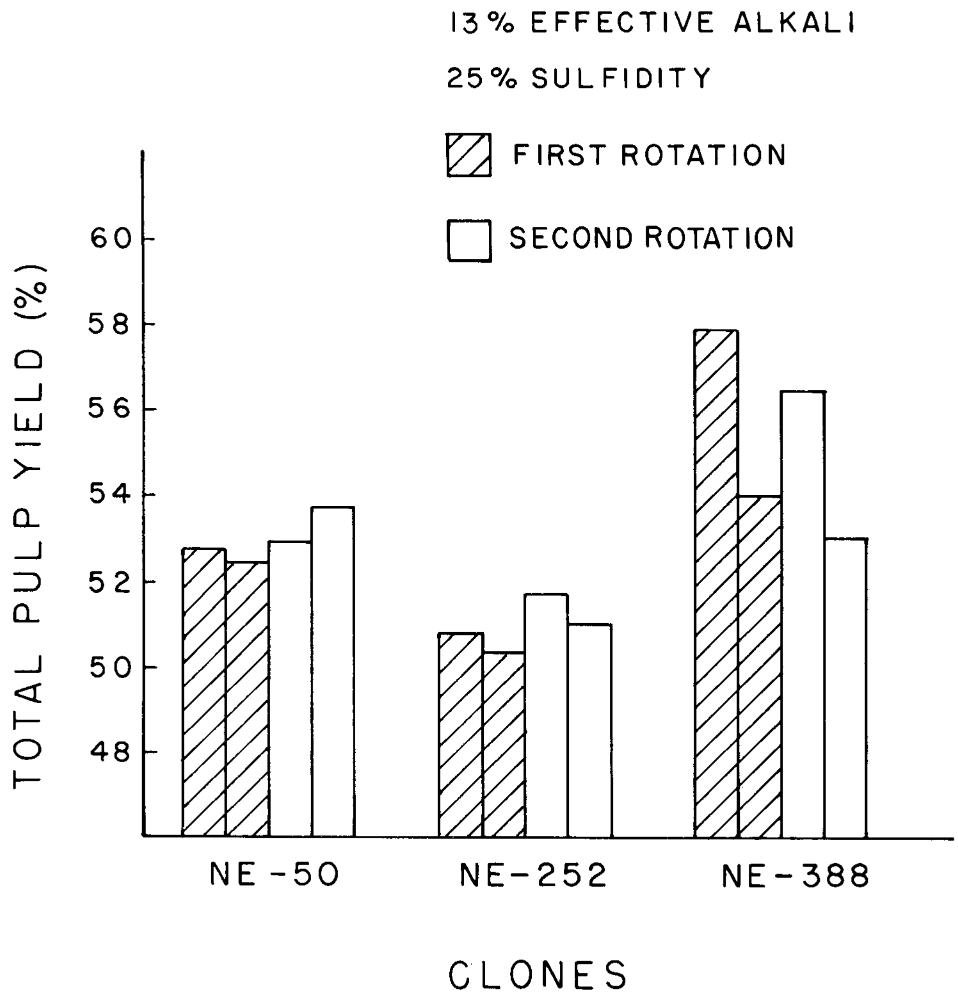

FIG. 3. Trial 2—Total pulp yields (%) of three *Populus* hybrids digested with 13% effective alkali.

An attempt was made to correlate the chemical composition of wood (first rotation clones) to the yield of pulp (trial 1). Earlier chemical evaluation studies by Murphey and coworkers (1979) were conducted on these parentages in a first rotation, and they found the specific gravity, extractives, and holocellulose content did not differ significantly among clones. Apparently, the differences observed in pulp yields in our study were due to the residual lignin contents of digested wood.

No significant differences ($P \leq 0.05$) in pulp yield were observed between first and second rotation, although slightly higher yields were consistently measured for second rotation trees. Slightly higher pulp yields for second rotation total tree chips may be by chance or possibly be attributed to the amount of bark obtained in the total tree chips. It can be expected that coppice forest methods would produce chips containing more bark than vegetative propagation methods. An

TABLE 3. *Fiber length of hybrid poplar pulp by Clark classification (%).*

Pulp	Screen openings (mm)				
	1.41	0.595	0.297	0.149	Overflow
Clone 388 (1st)	1	3	30	35	31
Clone 388 (2nd)	1	1	28	38	32
Clone 252 (1st)	nil	1	28	35	26
Clone 252 (2nd)	nil	nil	35	36	29
Clone 50 (1st)	nil	nil	35	36	30
Clone 50 (2nd)	nil	nil	31	37	32

TAPPI Standard T2330S-75.

increase in the amount of bark in the total tree chip composition increases chemical consumption by the bark during digestion, which results in pulps with a higher residual lignin content. Permanganate numbers of digested pulps from trial 1 tend to support these findings (Table 2). Clark classification studies also tend to indicate that second rotation total tree chips contained more bark than did first rotation total tree chips, based on the amount of fines lost during classification (Table 3).

Fiber length distribution was measured in each pulp, and no major differences were detected among the pulps evaluated (Table 3). A large proportion of the fibers, however, passed through the 0.149-mm screen, indicating a high preponderance of fines in juvenile *Populus* pulps. A similar observation was reported by others who found that a high percentage of fines occurred in total tree *Populus* chips as opposed to debarked chips (Murphey et al. 1979; Zarges et al. 1980).

Each pulp was Bauer disk-refined, and CSf was measured (Table 4). No large differences in refining response were observed among pulps evaluated. However, of major concern was the low initial CSf for disk-refined pulps. These results suggest that pulp drainage on the wire could be a problem due to the fines component of the pulp. If juvenile *Populus* hybrid pulps are to be considered as part of the furnish, possible changes in the arrangement of drainage elements on the wire may be necessary to maintain proper paper machine performance.

Handsheet evaluations

Handsheet strength properties were regressed against CSf for each rotation in each of the three clones, and statistical comparisons were made between the two regression equations (rotation 1 versus 2). The data are summarized in Table 5.

TABLE 4. *Refining response (CSf) of hybrid poplar kraft pulp using a Bauer disk refiner (0.015 inch plate clearance).*

No. of passes	NE 50		NE 252		NE 388	
	First	Second	First	Second	First	Second
2	566	545	527	550	578	527
9	493	501	487	520	505	475
16	443	447	447	480	473	430
23	420	431	404	457	428	371

TABLE 5. *Regression analysis and corresponding coefficient with comparisons of two regression lines for handsheet tensile, tear and burst properties.*

		Y = a + bx								
		Tensile (lb) = x			Burst factor = x			Tear factor = x		
Clone	Rotation	a	b	r	a	b	r	a	b	r
NE 50	1	199	−0.244	0.97*	56.7	−0.076	0.59	84.8	−0.069	0.64
	2	238	−0.285	0.87	56.7	−0.076	0.53	80.8	−0.054	0.71
NE 252	1	191	−0.190	0.92*	53.5	−0.071	0.82	67.3	−0.013	0.50*
	2	201	−0.234	0.91	57.7	−0.077	0.79	60.4	−0.008	0.48
NE 388	1	217	−0.259	0.88	70.2	−0.105	0.89	97.7	−0.065	0.51
	2	267	−0.334	0.91	52.5	−0.061	0.88	90.3	−0.055	0.97

* Significant differences ($P \leq 0.05$) between regression lines.

Significant differences ($P \leq 0.05$) in handsheet tensile properties were observed between rotations for clones 50 and 252; however, no differences were observed for clone 388. In addition, significant differences in handsheet tear were observed only for clone 252. No statistical differences in handsheet burst were observed between rotations for all three clones.

Difficulties were encountered in the interpretation of the pulp strength results with tree rotations. Generally, trees with the lowest specific gravity (faster growing trees) give pulps of highest values in tensile and burst (Marton et al. 1968). Since significant gains in tensile properties were observed for two of the three clones, similar trends were also expected for burst properties. This was not observed in this study. One possible explanation for the gains in tensile properties observed for two of the three clones may be, in part, due to a better growth response and cell development from sprouts regenerated from the stumps as opposed to vegetative propagation.

Significant differences ($P \leq 0.05$) in handsheet tear were observed between rotations for clone 252 but not clones 50 and 388. Earlier studies with these clones did indicate that parentage and age had a significant effect on mean fiber length (Murphey et al. 1979). These observations also suggest that for some clones, tree rotation may have an effect on mean fiber length since significant improvements in tear properties were observed for clone 252. For future studies, it would be of interest to measure mean fiber lengths with succeeding tree rotations.

A decrease in CSf level with refining resulted in a continuous improvement in tensile, burst, and tear properties. Increases in tensile and burst were expected; however, this was not expected for tear. Tear properties usually decrease, particularly at the low CSf levels. This loss in tear strength is attributed to the fiber shortening that occurs during refining. Apparently, minimal fiber cutting occurred during refining, resulting in an improvement in tear properties for all pulps.

Also to be considered is the fact that errors in interpretation may result because of the amount of debris in pulp. This has been observed and reported by other investigators (Clark 1970; Zarges et al. 1980). Debris in pulp depresses freeness value and does not give a suitable assessment of the treatment of fibers in refining. Such difficulties in interpretation of strength data indicate the need to develop alternative methods to better understand and evaluate pulp quality obtained from SRIC systems.

CONCLUSIONS

No significant differences ($P \leq 0.05$) in total pulp yields were measured between tree rotations; however, significant differences ($P \leq 0.05$) were measured among clones. Improvements in handsheet strength properties for second rotation pulps for some clones may be due in part to a better growth response and cell development for sprouts regenerated from the stumps as opposed to vegetative propagation.

Difficulties in paper machine operation may be encountered because of the preponderance of fines and debris found in both first and second rotations of *Populus* total tree pulps. Low CSf levels with minimal refining indicate that some adjustments for paper machine operation may be necessary to accommodate this type of pulp in the furnish.

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