PULP AND PAPERMAKING PROPERTIES OF A HYBRID POPLAR CLONE GROWN UNDER FOUR MANAGEMENT STRATEGIES AND TWO SOIL SITES[1]

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ABSTRACT

A study was undertaken to evaluate the pulp and papermaking properties of short rotation intensive culture (SRIC), three-year-old, *Populus* hybrid grown under four management strategies (control, irrigation, fertilization, and fertilization/irrigation) on two sites with either favorable or unfavorable inherent conditions for high biomass yields. No large differences in total pulp yields were observed with management strategy, although the fertilization/irrigation growth strategy produced debarked chips that gave slightly higher total pulp yields with lower permanganate numbers than did debarked chips obtained from the other three growth strategies. In addition, no significant differences ($P \leq 0.05$) in total kraft pulp yields were observed between sites. As expected, the wood/bark chip mixture for each management strategy and site produced significantly lower pulp yields with higher permanganate numbers compared to the debarked chips.

Handsheet strength evaluation studies were conducted using these pulps, and no statistical differences in handsheet breaking length, tear, burst, and M.I.T. fold were measured among management strategies or sites. However, longer fibers were measured from wood obtained from trees grown on the Basher (favorable) site. No statistical differences in handsheet properties were measured between debarked and total tree pulps. Results of this study indicated that neither the growth management strategy nor the soil site influenced handsheet strength properties for three-year-old *Populus* hybrid. These observations imply that the silviculturalist should grow SRIC *Populus* trees that produce the highest biomass yield at lowest possible cost.

Keywords: Hybrid poplar, management strategies, pulp, papermaking, soil sites.

INTRODUCTION

Short rotation intensive culture (SRIC) poplar plantations have potential for application as a raw material supply for the pulp and paper industry (Crist 1983; Nielson 1981; Zavitkovski and Dawson 1978). Previous studies have shown that satisfactory kraft pulping characteristics can be obtained from various poplar species grown on rotations as short as five years (Marton et al. 1968; Zarges et al. 1980). Investigators suggest that rotations of less than four years' duration may not be suitable because of lower wood density, tension wood, inferior pulp yield as well as relatively high bark contents (Kerridge et al. 1979; Isebrands and Parham 1974).

Recent studies showed that kraft pulp yield differences occurred among three-

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TABLE 1. *Kraft pulping conditions used in the M/K Systems Mini-Mill Laboratory Digester.*

Minutes to temperature	50
Minutes at temperature	120
Maximum temperature (°C)	172
Chip charge (grams)	500
Effective alkali (%)	18
Sulfidity (%)	25
Liquor to wood ratio	5:1
Minutes for cool-down	15

year-old *Populus* clones, suggesting that there is an opportunity to improve wood and pulp quality through genetic selection at a very early tree age (Labosky et al. 1983; Murphey et al. 1979). Since wood and pulp quality is influenced by genetic selection and environmental conditions, the effect of silvicultural treatments on wood quality, particularly for the young SRIC plantations, requires additional attention by researchers. This paper reports on the pulp and papermaking properties of three-year-old *Populus* hybrid clone (NE-388) grown under four management strategies on two sites with either favorable or unfavorable inherent conditions for high biomass yield. To date, pulp evaluation studies on SRIC hybrid poplar using side-by-side growth management strategies on two dissimilar sites have not been reported.

MATERIALS AND METHODS

Wood source

Populus hybrid plantations were established in central Pennsylvania in 1980 using the clone NE-388 (*Populus maximowiizii* × *trichocarpa*) containing a planting density of one tree per 0.48 m^2. This clone was selected because it exhibited reasonable growth yields with acceptable wood properties among clones evaluated in earlier work (Murphey et al. 1979; Bowersox and Ward 1976).

Three replicate plots were established for each of four growth management strategies (control, irrigation, fertilization, and fertilization/irrigation) on two soil sites representing conditions favorable (Basher silt loam soil) or unfavorable (Morrison sandy loam soil) for high biomass yields. Additional details on plantation establishment and management have been described by Blankenhorn et al. (1981).

SRIC trees were harvested at random from each replicated plot and plantation strategy during the 1982–1983 dormant season. The stems were harvested just before leaf emergence and combined in equal amounts to form a composite sample (3 replicates per plantation strategy). To maintain chip size and quality, chips containing wood only and a wood-bark mixture (total tree chips, containing 23–33% bark) were prepared with a guillotine cutter. Bark was removed by steaming the harvested stems at 115 C for 15 to 30 minutes at atmospheric pressure. After steaming, the bark was easily separated from the wood and discarded. Chips were prepared from the treated stems and included both main stem and branchwood. Comparisons between chip treatments were made to evaluate the influence of bark on total pulp yields and papermaking properties from each plantation management strategy and soil site (2 soil sites × 4 management strategies × 2 chip conditions = 16 composites).

TABLE 2. *Total pulp yields (%) and permanganate numbers*[1] *obtained from pulping three-year-old* Populus *grown under four management strategies and two soil sites.*

	Chips with bark				Chips without bark			
	Basher site		Morrison site		Basher site		Morrison site	
Management strategy	Pulp yield (%)	Permanganate number	Pulp yield (%)	Permanganate number	Pulp yield (%)	Permanganate number	Pulp yield (%)	Permanganate number
Control	44.8	16.4	44.3	17.6	48.2	12.4	47.5	13.5
	40.8	15.0	41.0	16.8	48.8	13.0	48.0	11.7
	40.0	14.9	41.0	16.1	48.7	12.6	48.3	13.7
	43.4	15.4	39.2	14.8	48.6	12.7	47.9	13.0
	42.2	15.4	41.4	16.3				
Fertilization	41.7	14.3	41.7	15.5	47.9	13.6	48.5	11.9
	42.7	15.0	42.3	16.6	47.8	13.0	48.5	14.2
	43.1	16.4	41.0	14.0	48.0	12.5	48.8	14.3
	42.5	15.2	41.7	15.4	47.9	13.0	48.6	13.3
Irrigation	44.7	15.2	44.4	15.6	48.3	12.0	48.9	14.0
	42.5	15.7	40.4	16.5	49.0	12.3	49.2	12.1
	44.4	15.0	38.1	15.9	48.3	12.6	48.3	14.4
	43.9	15.3	43.3	16.4	48.4	12.3	48.8	13.5
			41.6	16.1				
Fertilization/ irrigation	42.6	13.6	45.1	15.8	49.8	9.4	49.5	11.7
	42.9	14.3	44.1	16.5	48.7	11.2	48.7	13.0
	44.4	15.8	43.3	15.3	49.9	11.9	48.7	12.6
	43.3	14.6	44.2	15.9	49.5	10.8	49.0	12.4

[1] Based on 25 ml of $KMnO_4$–TAPPI Standard T 214 m-50.

Pulping

Kraft cooks were prepared in triplicate from each composite sample and the kraft pulping conditions employed are summarized in Table 1. A fourth kraft cook was prepared on three of the eight bark/wood mixture composites because of the large pulp yield variation observed from this wood source. 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 T 214 m-50 was used to measure the permanganate number of the pulp.

Handsheet preparation and testing

The replicated kraft cooks for each wood chip source were combined to provide enough pulp for a valley beater charge of 361.1 oven-dry grams. The pulp was beaten according to TAPPI standard T 200 ts-66, with but one exception in that no British disintegrator was available. Pulp samples for freeness testing and handsheet preparation were withdrawn from the beater at beating intervals of 0, 5, 10, 15, and 20 minutes. Canadian standard freeness (CSf) was determined using TAPPI standard method T 227 m-58. Handsheets were prepared following TAPPI standard T 105 os-71, with the exception that a constant humidity room was not always available for drying. The handsheets were conditioned to a constant moisture content prior to testing for burst, M.I.T. fold, breaking length, and tear,

TABLE 3. *Chemical constituents*[1] *in three-year-old* Populus *hybrid.*

Specimen	Treatment	Chemical constituents[2] Ash	Extractives[3]	Holocellulose[4]	Klason lignin[5]
		Basher site			
Wood	control	0.44	4.78	85.98	16.56
	fertilization	0.51	5.08	81.33	17.83
	irrigation	0.50	5.05	83.49	18.07
	fertilization/irrigation	0.53	5.34	81.59	16.02
Wood/bark	control	1.41	18.02	71.80	18.39
	fertilization	1.33	17.74	76.21	18.09
	irrigation	1.63	17.92	71.39	18.32
	fertilization/irrigation	1.27	16.00	75.71	18.24
		Morrison site			
Wood	control	0.42	4.65	85.23	16.11
	fertilization	0.43	4.34	80.67	18.02
	irrigation	0.44	4.65	82.37	18.22
	fertilization/irrigation	0.46	4.39	86.15	15.88
Wood/bark	control	1.45	14.63	73.54	18.36
	fertilization	1.37	12.80	72.65	15.62
	irrigation	1.14	13.64	72.93	17.75
	fertilization/irrigation	1.10	11.83	75.01	16.60

[1] Based on % of oven-dry weight.
[2] Taken from Blankenhorn et al. (1984b).
[3] ASTM D-1105-56.
[4] Browning, B. L. 1967.
[5] ASTM D-1106-56.

according to TAPPI standard T 220 os-71, at Westvaco's Tyrone Papermill paper testing facilities.

Each of the handsheet strength properties was regressed against CSf for each wood chip source. Strength properties were determined at CSf values of 300, 350,

TABLE 4. *Biomass yields and estimated kraft pulp yields*[1] *per hectare for three-year-old* Populus *by management strategy.*

Tree component	Site	Treatment Control	Fertilization	Irrigation	Fertilization/ irrigation
		OD tonne/hectare			
Wood	Basher	7.0 a[2]	14.5 bc	11.2 b	15.3 c
(pulp yield)		(3.4)	(7.0)	(5.4)	(7.3)
	Morrison	5.0 a	12.6 b	5.7 a	14.5 bc
		(2.4)	(6.0)	(2.7)	(7.0)
Total tree[3]	Basher	11.4 a	22.0 bc	17.1 b	22.5 c
		(4.8)	(9.2)	(7.2)	(9.4)
	Morrison	8.6 a	19.1 c	9.1 a	21.4 c
		(3.6)	(8.0)	(3.8)	(9.0)

[1] Estimated pulp yields per hectare based on average kraft pulp yields obtained at constant cooking conditions for debarked and total tree chips.
[2] Treatment means within and between sites with a common letter within tree components are not significantly different at the 0.05 level. Taken from Bowersox et al. (1984).
[3] Total tree includes wood, bark and branchwood. Leaves are not included in the oven-dry yields.

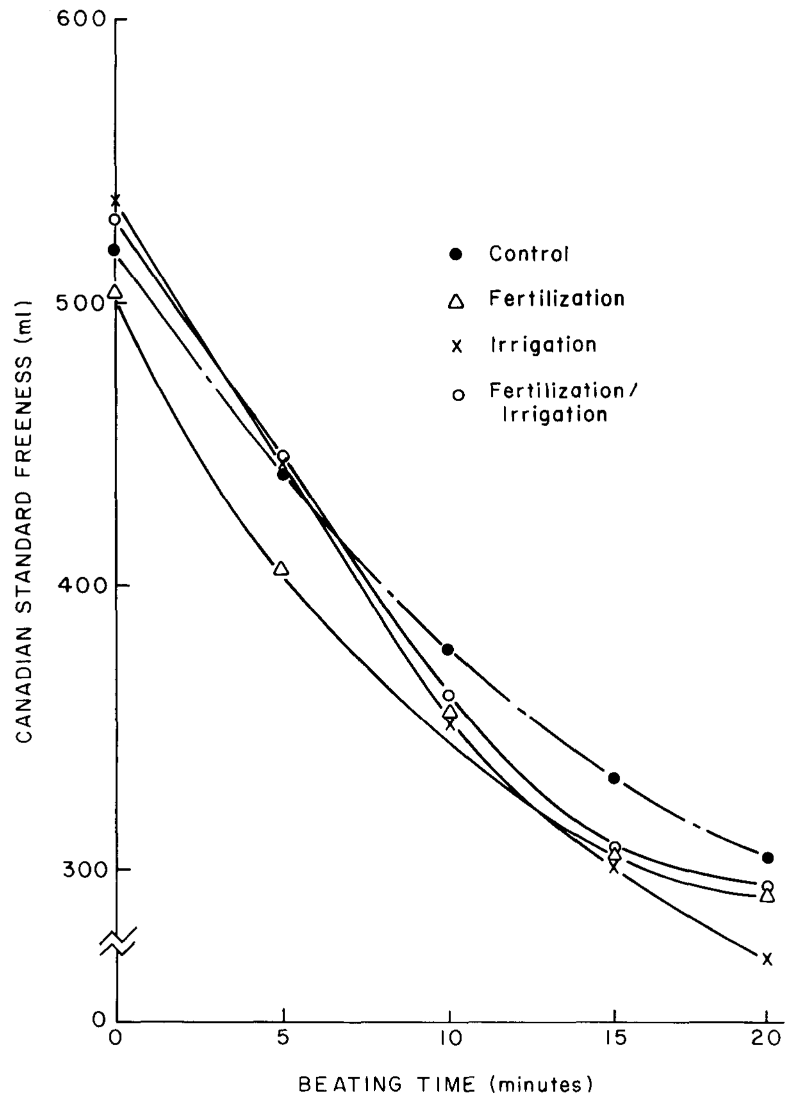

FIG. 1. Influence of beating time on CSf of all pulps made from *Populus* wood grown under the four management strategies.

400, and 450 from the plotted curves. At each CSf level, the strength property data were extrapolated and analyzed using a three-way (site × growth strategy × bark) analysis of variance (ANOVA) in the Statistical Analysis System (1982). Differences among means were determined by Duncan's multiple range test.

Fiber length analysis

Wood samples were taken approximately two feet from the base of each sample tree and macerated with peracetic acid/peroxide. Fiber lengths were determined for each growth management strategy/soil site combination of SRIC trees using a Projection Model 4002 Micro Macro Projector with a Numonics Model 1250

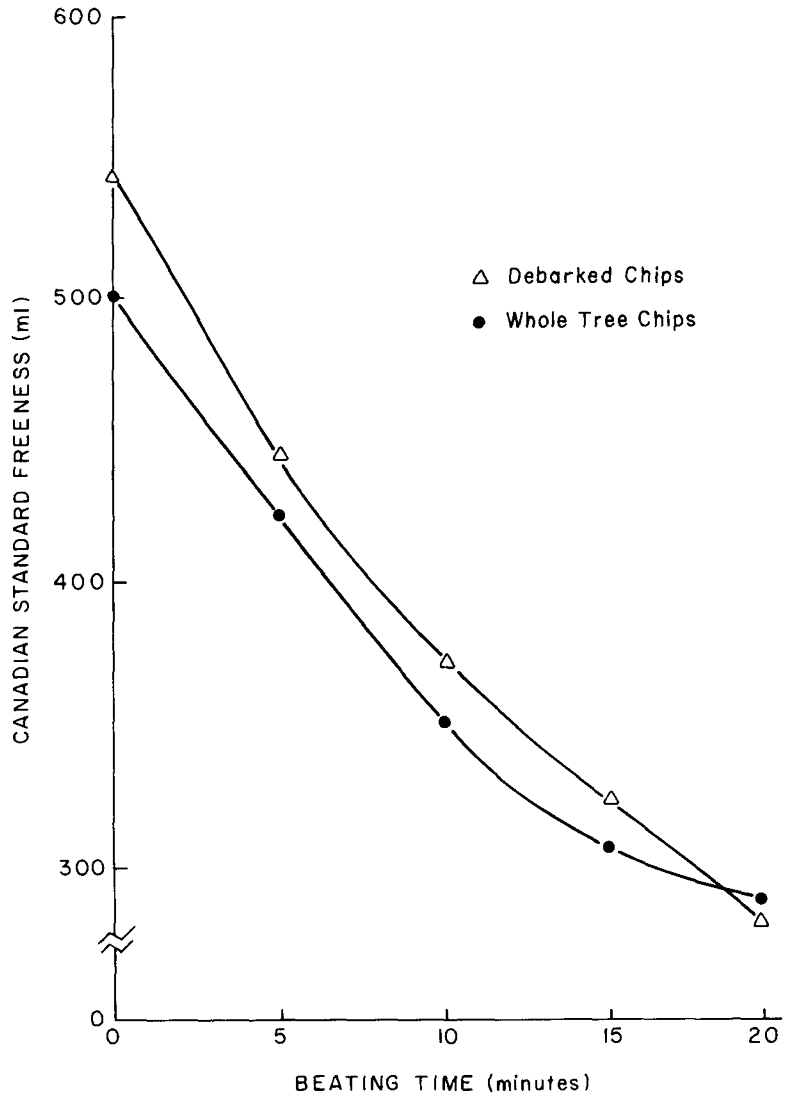

FIG. 2. Influence of beating time on CSf of pulps made from total tree and debarked *Populus* wood chips grown under the four management strategies and two soil sites.

Digitizer at Hammermill's Erie paper testing facilities. A minimum of one hundred fibers were measured from each sample. These data were analyzed using a two-way (site × growth strategy) ANOVA in the Statistical Analysis System (1982).

RESULTS AND DISCUSSION

Total kraft pulp yields and permanganate numbers obtained from pulping three-year-old *Populus* trees grown under the four management strategies and two soil sites are summarized in Table 2. Average pulp yields ranged from about 42% to 48% depending on the method of chip preparation.

No statistical differences ($P \leq 0.05$) in total pulp yields were measured among

TABLE 5. *Predicted handsheet strength properties obtained from debarked* Populus *chips grown under four management strategies and on two soil sites and compared at four CSf levels.*

Soil site and management strategy	Strength properties: Breaking length (km) CSf[1] 450	400	350	300	Tear (tear factor) CSf[1] 450	400	350	300	Burst (burst factor) CSf[1] 450	400	350	300	M.I.T. fold CSf[1] 450	400	350	300
Basher site																
Control	4.5	4.7	5.1	5.4	51	57	64	71	19	25	32	38	4	9	27	75
Fertilization	4.7	5.3	5.8	6.3	55	60	65	69	23	32	40	48	5	14	57	184
Irrigation	4.2	4.5	4.9	5.3	62	65	68	71	18	26	35	43	6	12	28	64
Fertilization/ irrigation	3.9	4.5	5.0	5.6	56	60	64	68	22	24	28	38	9	11	20	45
Morrison site																
Control	4.0	4.5	5.0	5.5	49	54	59	65	12	20	30	37	3	4	11	36
Fertilization	4.0	4.6	5.3	5.8	67	69	70	72	19	25	32	39	4	7	16	41
Irrigation	4.3	5.1	5.9	6.6	55	62	66	72	22	30	38	47	4	9	28	84
Fertilization/ irrigation	4.5	4.9	5.3	5.7	55	63	71	79	23	30	38	45	6	13	24	48

[1] Canadian Standard freeness (ml).

growth strategies, although the fertilization/irrigation strategy produced debarked wood chips that yielded slightly higher pulp yields with lower permanganate numbers. In addition, no statistical differences in kraft pulp yields were measured between chip composites obtained from the Basher and Morrison sites (Table 2). Statistical differences, however, in total pulp yields and permanganate numbers were measured between kraft digested total tree chips and debarked chips (Table 2). Pulp yields ranged from a high of 44.8 to a low of 38.0% for total tree chips, whereas pulp yields obtained from debarked chips ranged from a high of 49.9 to

TABLE 6. *Predicted handsheet properties obtained from total tree* Populus *chips grown under four management strategies and on two soil sites and compared at four CSf levels.*

Soil site and management strategy	Strength properties: Breaking length (km) CSf[1] 450	400	350	300	Tear (tear factor) CSf[1] 450	400	350	300	Burst (burst factor) CSf[1] 450	400	350	300	M.I.T. fold CSf[1] 450	400	350	300
Basher site																
Control	4.2	4.5	5.0	5.9	47	53	58	64	16	20	29	47	6	9	30	90
Fertilization	3.9	4.6	5.2	5.9	51	55	59	63	14	21	28	35	4	7	21	52
Irrigation	4.4	4.8	5.2	5.7	55	60	52	63	20	24	30	36	9	16	26	44
Fertilization/ irrigation	4.4	4.8	5.3	5.7	51	56	60	65	19	26	34	42	8	12	22	49
Morrison site																
Control	4.0	4.4	4.8	5.2	65	69	72	75	17	20	24	32	4	6	14	34
Fertilization	4.5	4.8	5.2	5.2	56	60	62	64	20	26	33	39	11	17	33	80
Irrigation	5.3	5.4	5.4	5.4	51	53	55	58	17	22	27	33	15	21	28	31
Fertilization/ irrigation	4.7	5.2	5.7	6.1	55	58	62	65	17	23	29	35	7	8	12	32

[1] Canadian Standard freeness (ml).

TABLE 7. *Fiber lengths obtained from* Populus *grown under four management strategies and from two soil sites.*

Soil site and management strategy	Number of fibers							Average length (mm)
	Fiber length range (mm)							
	0.00–0.25	0.25–0.50	0.50–0.75	0.75–1.00	1.00–1.25	1.25–1.50	1.50–1.75	
Basher site								
Control	0	7	66	33	4	1	1	0.717
Fertilization	1	22	70	35	10	1	0	0.686
Irrigation	0	20	68	41	5	0	0	0.683
Fertilization/ irrigation	0	21	60	55	5	0	0	0.703
Morrison site								
Control	0	35	79	25	0	0	0	0.603
Fertilization	0	30	66	25	5	1	0	0.641
Irrigation	1	22	72	21	2	0	0	0.627
Fertilization/ irrigation	0	25	58	33	8	0	0	0.673

a low of 47.5%. The average permanganate numbers for debarked and total tree chips were 12.6 and 15.6, respectively. The kraft pulp yield results observed in this study are in general agreement with those results reported in the literature (Zarges et al. 1980; Marton et al. 1968; Labosky et al. 1983). Kerridge and coworkers (1979) reported that hybrid poplars grown in rotations of one to four years do produce lower pulp yields because of the lower wood density associated with this wood.

Lower pulp yields were expected from pulping total tree chips because of the presence of bark in the chip mixture. Zarges and coworkers (1980) reported that both bark and twigs substantially lowered pulp yields. Similar observations have been reported by Einspahr and coworkers (1979) working with pulps obtained from hickory wood/bark mixtures. Blankenhorn et al. (1984b) found the amount of bark to total tree weight to vary depending on tree age, management strategy, and site. They reported a bark weight of 23–33% based on total tree weight for three-year-old *Populus* trees.

Chemical evaluation studies by Blankenhorn and coworkers (1984a) found that significant differences in chemical content occurred among management strategies for a given component of clone NE-388 (Table 3). No significant differences, however, were found to occur between the chemical content values for the Basher and Morrison sites. A threefold difference in extractives content was measured between wood and wood/bark mixtures. Therefore, it can be concluded that the combination of low fibrous yields and high extractive content for the bark component in the wood-bark composite resulted in the reduced yield for total tree chips. In addition, it should also be mentioned that these pulps may take longer to wash because of the higher fatty acid content associated with bark extractives (Zarges et al. 1980).

Another problem associated with high levels of bark in wood chips is that bark consumes much alkali during wood digestion, thus reducing the amount of available chemical to dissolve the lignin in wood and bark (Rydholm 1965). This situation was evident considering the fact that under identical cooking conditions, the total tree chips produced pulps with lower yields and higher permanganate numbers than did debarked wood chips.

Although pulp yields were not significantly influenced by management strategies, biomass production is strongly influenced by silvicultural treatments (Nielson 1981; Crist 1975; Einspahr 1971). Bowersox et al. (1984) found in their work with three-year-old *Populus* clone (NE-388) that statistical differences occurred in biomass yield among growth management strategies and soil sites (Table 4). Combining the biomass yields with kraft pulp yields for total tree and debarked wood chips resulted in an estimate of the kraft pulp yield per hectare (Table 4). Based on these observations, it can be reasoned that statistical differences in pulp yields per hectare would also occur among growth strategies and sites and would vary according to the biomass yield observed in their study.

Pulp refining

The influence of Valley beating time on CSf of all pulps obtained from *Populus* wood grown under the four growth management strategies is shown in Fig. 1. No large differences in CSf values were observed among growth management strategies and sites; however, differences between CSf and beating time were observed between debarked and total tree chips (Fig. 2). Lower initial CSf values after beating intervals of 5, 10 and 15 minutes were attributed to the amount of debris and fines associated with pulping bark (Zarges et al. 1980). Clark classification studies on these pulps support earlier findings in that the amount of fines were high for both total tree chips (Labosky et al. 1983; Zarges et al. 1980). These results suggest that pulp drainage on the machine wire could be a problem resulting in lower paper machine operating speeds.

Handsheet properties

Handsheet strength properties were regressed against CSf for each growth strategy; soil site and chip type and the predicted results are summarized in Tables 5 and 6. ANOVA results showed no statistical differences in handsheet breaking length, tear, burst, and M.I.T. fold were measured among the four growth strategies and site. In addition, no statistical differences in handsheet strength properties were measured between total tree chip pulps and debarked pulps.

Other studies have shown that the effects of bark debris on handsheet strength properties depended on the wood species (Brown 1956; Einspahr et al. 1979; Zarges et al. 1980). Zarges et al. (1980) found *Populus* paper strength of whole tree pulp to be significantly lower at a given CSf level than for debarked stemwood pulp. They attributed the reduction in strength to the larger amount of debris in whole-tree pulps. This was not observed, and strength comparison at the 350 CSf level showed a breaking length of about 5.5 km in this study, whereas Zarges et al. (1980) reported a breaking length of about 9 km for 5- to 7-year-old *Populus*. The strength differences observed between the two studies can be attributed to the age of the juvenile wood pulped and examined (5 to 7 years old versus 3-year-old *Populus*).

Fiber length distribution studies were made on debarked wood chips, and no statistical differences in fiber length occurred among growth strategies (Table 7). However, statistical differences in fiber lengths were measured from wood obtained from the two soil sites. The average fiber lengths were 0.696 mm and 0.635

mm for the Basher and Morrison sites, respectively. Handsheet strength evaluation studies, however, did not exhibit differences between sites, indicating that these slight improvements in pulp quality were masked by the inherently weak pulp and variability in testing.

In summary, these results suggest that the silvicultural practices used to grow 3-year-old SRIC *Populus* hybrids would not be a factor affecting sheet properties, although slight improvements in pulp quality were measured. On the basis of these observations, it is recommended that the growth management strategy employed to grow *Populus* hybrid should be that which produces the highest biomass yield at the lowest possible cost.

CONCLUSIONS

1) No large differences in total pulp yields were observed, although the fertilization/irrigation growth strategy produced debarked wood chips that had slightly higher pulp yields with lower permanganate numbers than did wood chips obtained from the other three growth strategies.

2) As expected, under identical kraft digestions debarked chips produced significantly higher pulp yields with lower permanganate numbers than did the wood/bark chip mixture.

3) No statistical differences in total kraft pulp yields were observed between sites.

4) Longer fibers were measured from the trees grown on the Basher site (better) compared to trees grown on the Morrison site.

5) At a given CSF level, no statistical differences in handsheet breaking length, burst, tear, and M.I.T. fold were measured among growth strategies, sites or total tree/debarked wood chip mixtures.

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