The Impact of Initial Tree Spacing on Wood Fiber and Pulp Properties

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Introduction

Relationships between basic tree and wood properties, and species, seed source, geographic location, site conditions and management decisions are very complex. The objective of this study was to quantify the effects of forest management practices on wood fiber and pulp properties in jack pine (*Pinus banksiana* Lamb.), one of the most important commercial species in Northern America.

A better understanding of the relationship between initial spacing and wood and end-product quality should help define improved forest management strategies required to produce quality wood and products in the future.

Materials and Methods

Trial description and sample trees

The oldest jack pine initial spacing trial in North America was established by the USDA Forest Service in the spring of 1941 near Wellston in Manistee County, Michigan, USA. The planting site was a level (flat), abandoned field consisting of Grayling sand, which is typical of the poorer sandy soils planted to jack pine in northern Lower Michigan. The planted area was a ten–acre planting block divided into twenty–five 0.4 acre square plots. The plots were all planted with jack pine (1–0) of a common, local–seed origin at five different initial spacings: 0.45 x 0.45 m (1.5 x 1.5), 0.9 x 0.9 m (3 x 3), 1.5 x 1.5 m (5 x 5), 2.1 x 2.1 m (7 x 7), and 2.7 x 2.7 m (9 x 9). Each of the five spacing trials was replicated five times, in the form of a Latin square. After the 14^{th} year of growth, select plots were pre–commercially thinned. The current study examined three initial spacings: 1.5 x 1.5 m, 2.1 x 2.1 m, and 2.7 x 2.7 m, and one 1.5 x 1.5 m spacing that was pre–commercially thinned to 2.1 x 2.1 m at age 14 in order to evaluate the impact of both initial spacing and pre–commercial thinning on wood fiber and pulp properties.

<u>Wood chips</u>

The 8–foot–long logs were processed identically to commercial production, but at a reduced speed in order to keep track of each log and resultant lumber. The remaining slabs were individually collected and chipped in a CAE 36–inch 10' knife disc chipper. Only chips originating from the slab wood of the lower 4 m of the tree were used for the fiber and pulping studies. To give a general representation of the DBH class, this study examined the fiber and pulp properties from three DBH groups: small–size tree (DBH class of 12 cm); medium–size trees (DBH class of 18 cm) and large–size trees (DBH class of 24 cm). The pooled wood chips were thoroughly mixed for each sample and further screened on an EMP/Wennberg Chip Classifier to obtain accept chips in the thickness range from 2 to 6 mm, as well as to remove oversized and fines material. The wood chips were then allowed to air– dry to equilibrium moisture content in a controlled humidity room.

Chemical (kraft) pulping

Laboratory scale kraft pulping was performed in duplicate using the equivalent of 30-g oven-dried wood in a 500-ml pressurized reactor in a circulating oil-thermo- static bath. Pulping conditions were: 18.3% active alkali, 16% effective alkali, 25% sulfidity, a 4.5:1 liquor-to-wood ratio, 30-min ramp to temperature, and maintained at 170° C for varying time periods to achieve three different H-factors: 1000, 1500, and 2000. The cooked wood chips were then washed extensively with water and blended for 15 min in a standard British disintegrator. The resulting pulp was filtered and washed until the filtrate water was clear. Pulps were then dried overnight at 50° C prior to weighing for total pulp yield, where total pulp yield was determined as the ratio of the oven-dry mass of the produced pulp to the oven-dry mass of wood chips before cooking.

Pulp analysis

Kappa numbers (residual lignin) and pulp viscosity were determined using the TAPPI standard method T236 om-99 and T230 om-94, respectively. Fiber length and coarseness were measured on a Fiber Quality Analyzer (OpTest Equipment Inc., Canada)

Results and Discussion

Pulp yield

When a comparison was made at the similar H-factors, it was apparent that pulp yields were greater with higher stand densities (Fig. 1). However, this was anticipated from the chemical analyses of the wood, as these trees inherently displayed elevated cellulose (glucose) concentrations (Kang *et al.* 2004).

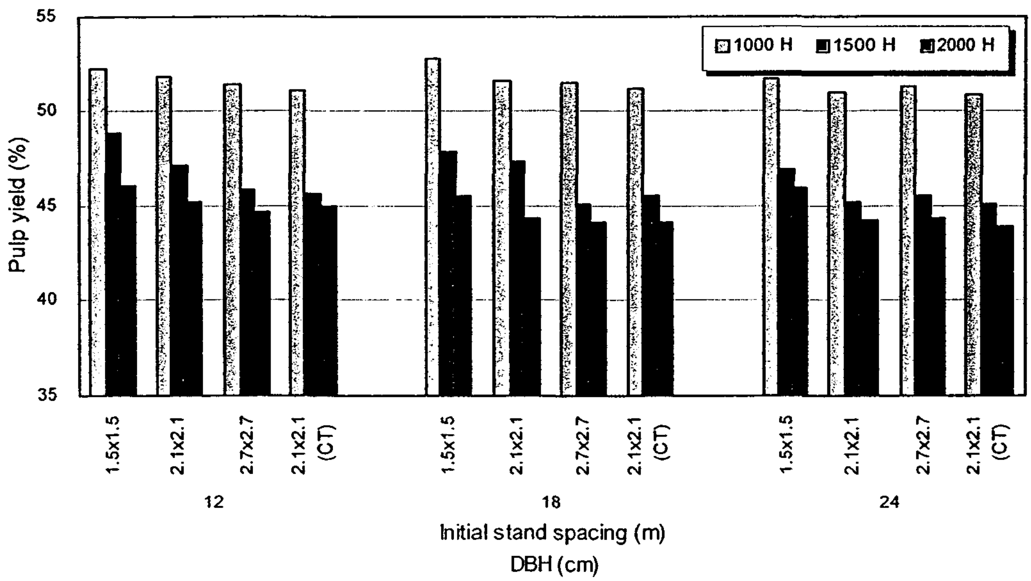

Fig. 1. Changes in pulp yield of jack pine grown at different initial stand densities at different H-factors.

There was roughly a 1% difference in pulp yield recovery when comparing trees originating from 1.5 x 1.5-m versus 2.7 x 2.7-m initial spacing. Additionally, there was little difference in pulp yield of trees of different DBH classifications when compared at the same H-factor. Interestingly, trees that originated from the stand that was subject to pre-commercial thinning consistently showed lower yields than trees originating from the other stands.

Kappa number

In contrast to the results of pulp yield, a comparison of residual pulp kappa at a given H-factor demonstrated an opposite trend: trees that originated from lower density stands had lower residual lignin (kappa) than trees from high density stands (Table 1). Clearly, kappa is related to wood density, more so than lignin content, as trees originating from lower stand density demonstrated the lowest overall tree density, but highest wood lignin content. This trend was consistent at all DBH classes. Similarly, the trees that were pre-commercially thinned generally demonstrated the lowest kappa number at a given H-factor, supporting the density relationship, as these trees also had the lowest overall wood density (Kang *et al.* 2004). Clearly, the rate of delignification during the chemical pulping of jack pine wood chips from wide spacing (lower stand density) proceeds more easily and to a greater extent than that from narrow spacing.

Pulping efficiencies and fiber properties

Table 2 illustrates the pulping efficiencies and ensuing fiber properties when these same jack pine trees were pulped to a target kappa of 30, an industrially relevant residual lignin content for fine papermaking. Table 2 clearly demonstrates that at a defined chemical loading there is a significant difference in the H-factor (time) required to attain a set kappa when comparing the effects of initial stand spacing. Trees that were planted at a higher stand density require ~ 200 H-factor greater to achieve a comparable level of delignification. However, these same trees also realize a slight yield gain (~0.5%). Employing a target residual kappa as a benchmark demonstrates an interesting trend when comparing trees of different DBH classes; larger trees seem to delignify with greater efficiency than trees of smaller DBH.

Table 1. Changes in pulp properties of jack pine grown at different initial stand densities at different H-factors.

DBH (cm)	Initial spacing (m)	Variable			
		H-factor	Kappa	Fiber length [a] (mm)	Coarseness (mg/m)
12	1.5 X 1.5	1000	47.5	3.31	0.414
		1500	33.3	3.00	0.259
		2000	25.9	2.94	0.219
	2.1 X 2.1	1000	45.8	3.08	0.374
		1500	30.4	2.96	0.251
		2000	24.0	2.89	0.202
	2.7 X 2.7	1000	42.4	2.97	0.364
		1500	28.7	2.80	0.222
		2000	21.8	2.74	0.182
	2.1 X 2.1 (CT) [b]	1000	41.7	2.91	0.359
		1500	28.8	2.83	0.234
		2000	22.2	2.78	0.191
18	1.5 X 1.5	1000	48.8	3.10	0.373
		1500	32.5	2.99	0.245
		2000	23.4	2.91	0.212
	2.1 X 2.1	1000	45.0	3.03	0.345
		1500	31.6	2.89	0.219
		2000	22.2	2.83	0.185
	2.7 X 2.7	1000	43.1	2.92	0.315
		1500	27.5	2.75	0.197
		2000	21.6	2.67	0.171
	2.1 X 2.1 (CT)	1000	42.3	2.88	0.294
		1500	28.1	2.79	0.209
		2000	21.8	2.74	0.177
24	1.5 X 1.5	1000	46.2	2.98	0.350
		1500	31.1	2.87	0.240
		2000	24.1	2.79	0.211
	2.1 X 2.1	1000	42.5	2.91	0.321
		1500	27.9	2.77	0.216
		2000	22.9	2.66	0.179
	2.7 X 2.7	1000	44.9	2.83	0.281
		1500	28.5	2.68	0.206
		2000	22.6	2.58	0.169
	2.1 X 2.1 (CT)	1000	43.7	2.85	0.302
		1500	27.5	2.65	0.181
		2000	21.9	2.55	0.161

[a] Length-weighted fiber length.

[b] 2.1 X 2.1-m spacing that was established by commercial thinning (CT) of the 1.5 X 1.5-m plot.

Table 2. H-factor requirement and pulp properties of jack pine grown at different initial stand densities pulped to a kappa 30.

DBH (cm)	Initial spacing (m)	Variable				
		H-factor	Pulp yield (%)	Fiber length [a] (mm)	Coarseness (mg/m)	Pulp viscosity (cP)
12	1.5 X 1.5	1757	47.4	2.97	0.245	17.5
	2.1 X 2.1	1655	47.0	2.95	0.249	19.3
	2.7 X 2.7	1548	46.9	2.83	0.247	19.5
	2.1 X 2.1 (CT) [b]	1544	46.9	2.83	0.254	17.0
18	1.5 X 1.5	1690	47.3	2.96	0.244	14.3
	2.1 X 2.1	1628	46.8	2.89	0.228	15.9
	2.7 X 2.7	1535	46.6	2.77	0.223	15.8
	2.1 X 2.1 (CT)	1537	46.7	2.80	0.222	17.7
24	1.5 X 1.5	1670	47.1	2.85	0.242	15.5
	2.1 X 2.1	1558	46.4	2.77	0.231	16.5
	2.7 X 2.7	1591	46.4	2.68	0.209	14.7
	2.1 X 2.1 (CT)	1546	46.3	2.67	0.208	16.3

[a] Length-weighted fiber length.
[b] 2.1 X 2.1-m spacing that was established by commercial thinning (CT) of the 1.5 X 1.5-m plot.

Paper properties are largely determined by the inherent properties of the wood fibers liberated during chemical pulping (K□renlampi and Yu 1997; Mansfield and Kibblewhite 2000), with fiber length contributing the greatest influence.

Length-weighted fiber length and coarseness of jack pine unbleached kraft pulps were measured to evaluate the quality of pulp fiber generated from the pulping trials (Table 1). It was clear that both fiber properties tended to decrease with increased initial spacing, as well as DBH. These fiber attributes are undoubtedly influenced by differences in growth rate as affected by different initial stand spacing. Trees grown at lower stand density have reduced pressure for competition in their growing environment, and as such the innate fiber properties of the tree are strongly influenced by the silvicultural strategy.

Similarly, when the trees of different DBH classes from different stand densities were compared at a target kappa (kappa 30), both fiber length and coarseness were greater for fiber originating from higher density stands (Table 2). Furthermore, trees with a larger diameter at breast height generally showed shorter fibers and lower fiber coarseness when compared to smaller diameter, higher density trees. Although only small differences exist, the increased fiber length will indeed influence the strength of paper generated from this resource. Table 2 also shows the effect of initial spacing on pulp viscosities when the wood chips were pulped to a given kappa; generally, the pulp viscosity was slightly higher for wood that originated from higher stand densities.

Conclusions

Total pulp yield, kappa number (residual lignin), fiber length, and coarseness of plantation jack pine unbleached kraft pulp were measured to evaluate the impact of initial spacing and pre-commercial thinning on pulping efficiencies and pulp fiber properties. The results clearly show that initial tree spacing has a significant effect on all of these properties, and thus it is possible to improve yield and pulp fiber properties of jack pine through stand density regulation.

Additionally, a positive effect of pre-commercial thinning on fiber properties was also demonstrated. As a consequence of these results, basic prescription information for decision-making in the establishment of jack pine plantations with desirable pulp properties can be elucidated.

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