USDA FOREST SERVICE
RESEARCH PAPER NC-157

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J. Zavitkovski and
David H. Dawson

North Central Forest Experiment Station
Forest Service, U.S. Department of Agriculture

We thank Drs. Rene Doucet, Alan Ek, and Thomas Rudolph for reviewing this manuscript and Daniel A. Netzer and Terry F. Strong for their help in collecting and processing the data.

North Central Forest Experiment Station
John H. Ohman, Director
Forest Service - U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108

Manuscript approved for publication October 27, 1977
1978

STRUCTURE AND BIOMASS PRODUCTION OF 1- TO 7-YEAR-OLD INTENSIVELY CULTURED JACK PINE PLANTATIONS IN WISCONSIN

J. Zavitkovski, *Principal Ecologist,*
and David H. Dawson, *Principal Plant Geneticist,*
Rhinelander, Wisconsin

New silvicultural practices will have to be introduced into United States forests to respond to the demand for fiber that is expected to double by the year 2000 (Auchter 1976). The Maximum Yield and Intensive Culture Project was established at the Institute of Forest Genetics in Rhinelander, Wisconsin, with the mission to study a short-rotation intensive culture (SRIC) system. In the SRIC system, agrotechniques, which greatly increased production of agricultural crops, are applied to forestry. Selected or improved tree species or hybrids are planted at close spacings and grown on short rotations under intensive care including site preparation, weed control, fertilization, and irrigation. Results of previous studies on *Populus* hybrids indicated that biomass production in SRIC plantations can be significantly increased in comparison to the production achieved in plantations or natural stands tended in the traditional way (Dawson *et al.* 1976, Ek and Dawson 1976).

The objectives of this study were to evaluate the suitability of jack pine (*Pinus banksiana*) for the SRIC system in the Lake States and to identify a combination of spacing and rotation at which the mean annual biomass production of stems and branches reaches its maximum. Jack pine was included in the SRIC studies because of its rapid juvenile growth and desirable wood properties for pulp and paper production.

METHODS AND MATERIALS

The plantations were established in 1970 at Rhinelander, Wisconsin, using tubelings grown from seed collected in southern Michigan. The seedlings were grown in plastic tubes in a greenhouse for 5 months and outplanted in June 1970. They averaged about 5 cm in height at the time of planting and, in spite of adequate irrigation and fertilization, grew only about 1 cm during the first growing season in the field. It became obvious that the plastic tubes restricted root development and seedling growth so the plastic tubes were removed in September 1970. Height growth in the second year improved but at age 2 the average height was at least 1 year behind in comparison to freely-developing seedlings raised under less intensive conditions (Jeffers and Nienstaedt 1973).

The plantations were established at 9- by 9-, 12- by 12-, and 24- by 24-in. spacings in plots 16 by 16 ft. in size. Each spacing was replicated three times. A 10-ft. wide weedless open space was left between replications and a 6-ft. wide open space was left between plots within each replication. A high level of soil nutrients was maintained by annual fertilization and soil moisture was kept near field capacity by irrigation, which was gauged according to the weather. In 1976 (an extremely droughty year), the irrigation had to be reduced to once a week (about 1/3 of the regular amount) and in mid-July it was discontinued.

During the first 3 years, heights and basal diameters (1 in. above ground) were measured on 150, 90, and 30 seedlings in plantings spaced 9- by 9-, 12- by 12-, and 24- by 24- in., respectively. At age 4 and 5, heights and diameter breast height (dbh) were measured on 54, 36, and 9 trees, and at age 6 and 7, on more than 300, 200, and 50 trees in the same spacings.

From 4 to 7 years, dry weights of tree components—stems, branches, needless, wood, and bark—were obtained on sample trees. At age 4 and 5, sample trees were harvested from a subplot in each plot, then dry weights of tree components were obtained for the subplot, and biomasses per hectare were calculated. Biomasses at ages 6 and 7 were obtained by regression techniques (allometry) (Zavitkovski *et al.* 1974). Briefly, dbh's were measured and the trees divided into three dbh classes. A sample of nine trees, one from each dbh class in each replication, was taken from plantings at each spacing at age 6 and a sample of three trees at age 7. All harvested trees were separated into stems, branches, and needles, dried at 70 C to a weight equilibrium, and weighed. Percentages of wood and bark in stems and branches, and percentages of current year's, older living, and dead branches and needles were obtained on three trees in each spacing. The allometric (double-logarithmic) (Zavitkovski 1971) and double-square-root (Schreuder and Swank 1973) growth models were fitted to the weight data with *dbh* or $(Dbh)^2$ *x height* as the independent variables. The biomass of each tree (or tree component) in each plot was calculated from the allometric regressions and the stand biomass obtained by the method of "every-tree-summation" (Baskerville 1965). All measurements and destructive sampling were done during the dormant season. Biomasses at ages 1 to 3 were approximated from allometric regressions between height and dry weight of 4-year-old seedlings.

The current annual increment (c.a.i.) of total tree or stem plus branch biomass refers to living trees only and was obtained by subtracting the biomass at age t from the biomass at age $t + 1$. The current annual production (c.a.p.) is defined as c.a.i. plus the biomass of trees that died during the year. The mean annual increment (m.a.i.) of total tree or stem plus branch biomass refers to living trees only and was obtained by dividing the biomass by current age. The mean annual production (m.a.p.) was obtained in the same manner as the m.a.i. but included the biomass of standing dead trees. The total or whole tree biomass refers to the above-ground parts of trees only.

Biases are inherent in studies on biomass production on small experimental forest plantings. The "edge effect" extended through several rows in all plots and was more severe in the dense plantings. In 1976 mortality percentages in rows 1 (border row), 2, 3, 4, and 5 through 11 of the 9 x 9-in. planting were 11, 23, 37, 41, and 59 percent. Diameters at breast height in the same rows were 23.3, 18.1, 18.1, 18.2, and 17.3 mm. Less pronounced gradients of mortality and dbh occurred in the 12- by 12- and 24- by 24-in. plantings. The bias in production statistics was reduced by excluding rows 1 and 2 in the 9- by 9- and 12- by 12-in. planting and row 1 and the 24- by 24-in. planting.

RESULTS AND DISCUSSION

Spacing and Height Growth

Height growth during the first 2 years was extremely slow because of the restrictive effect of plastic tubes on seedlings development. At the time of planting, the seedlings were 5 cm in height and they reached only 6 cm at the end of the first growing season and 17 to 19 cm at the end of the second (fig. 1). In genetics tests conducted in the same area by Jeffers and Nienstaedt (1973), 2-year-old jack pine averaged 50.1 cm. Our plants reached that height at age 3.

Our plants grew rapidly from age 2 to 7. By age 4 they were about 30 percent taller than field planted jack pine in Michigan (Canavera and Wright 1973); by age 5 they were about 50 to 75 percent taller than jack pine from Ontario (Yeatman 1974); by age 6 they equalled the height of 10-year-old plantations in lower Michigan

(Guilkey and Westing 1956); and at age 7, they were about as high as 12-year-olds in Wisconsin, Michigan, and Minnesota (King 1966). The average height of the 24 x 24-in. planting (3.50 m) approached that of a 15-year-old Michigan plantation established at 18 x 18-in. spacing (Guilkey and Westing 1956).

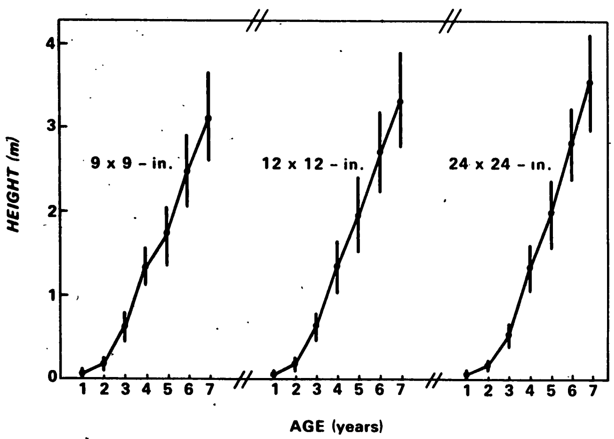

Figure 1.—*Height growth of 1- to 7-year-old jack pine at three spacings. Vertical bars indicate standard deviation.*

The effect of spacing on height growth showed up at age 5 and became significant at age 7 when the average height was 3.10, 3.31, and 3.50 m in planting spaced 9- by 9-, 12- by 12-, and 24- by 24 -in., respectively (table 1, fig. 1). However, the average height of dominant trees (3.50 m or more) in each planting—3.76, 3.81, and 3.85 m—was not significantly different. The same structural pattern was observed by Guilkey and Westing (1956) in 15-year-old plantations of jack pine in Michigan. Whereas the average height of all living trees in the densest planting (18- by 18-in.) was about 2 ft. less than in more widely-spaced plantings, the average height of dominant trees was about the same in all spacings.

The same height distribution pattern was also present in 15-year-old jack pine plantations established at four densities in Wisconsin (Wilde *et al.* 1968). The average height of the densest planting (24- by 24-in.) was about 2 ft. less than in plantings established at wider spacings. Wilde and coworkers ascribed that depression to a critical shortage of soil moisture. It seems, however, that the depression in height may have resulted from a competition light rather than for soil moisture. This point is supported by our studies in which soil moisture stresses were eliminated by irrigation. A severe competition for light was obviously the main reason for height growth depression in the 9- x 9-in. planting compared to the average height in the 24- x 24-in. planting.

Spacing and Diameter Growth

The basal and breast height (dbh) diameter growth increased with increased spacing (fig.2). At age 5 the dbh averaged 0.71, 0.97, and 1.16 cm in the 9- by 9-, 12- by 12-, and 24- by 24-in. spacing, respectively. The dbh doubled during the 6th year but then the increase slowed down during the 7th. The shape of the dbh curve for the 24- by 24-in. planting suggests a continuous steep increase in future years whereas dbh increases in the 9- by 9- and 12- by 12-in. plantings are likely to be small. The variability of dbh's was high and was especially high in the denser plantings where the competition for space was more severe.

Table 1.—*Structure and biomass yields of 7-year-old jack pine*

Spacing	Stand density: Initial	Stand density: Age 7	Survival	Average height	Average dbh	Total dry weight	Stem: Wood	Stem: Bark	Branches: Wood	Branches: Bark	Needles	Other[1]
Inches	*Trees/ha (Thousands)*		*Percent*	*m*	*cm*	*mt/ha*						
9 by 9	191.3	93.7	49	3.10[a2] (0.52)[3]	1.74[a] (0.75)	47.39[a] (5.26)	21.90	6.21	5.48	3.60	9.89[a] (0.69)	0.31
12 by 12	107.6	73.5	68	3.31[b] (0.58)	2.04[b] (0.84)	56.77[a] (6.58)	25.60	6.32	7.54	4.92	12.07[b] (1.44)	0.32
24 by 24	26.9	25.2	94	3.50[c] (0.56)	2.96[c] (0.99)	53.02[a] (13.16)	21.28	4.36	10.43	3.53	12.95[b] (3.72)	0.47

[1]Cones, buds, etc.
[2]Values (in columns) followed by the same letter are not significantly different (p=0.05).
[3]Standard deviation.

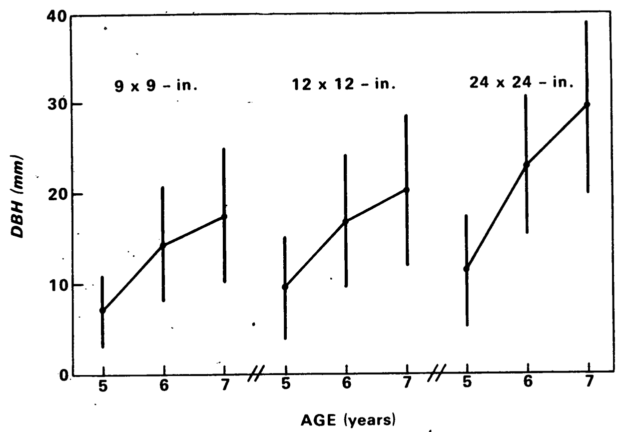

Figure 2.—*Dbh growth of 5- to 7-year-old jack pine at three spacings. Vertical bars indicate standard deviation.*

Diameter growth was more affected by spacing than was height growth. At age 7, the difference between heights in the 9- by 9- and 24- by 24-in. spacings was about 13 percent and was about 70 percent between dbh's (table 1). The same holds for several other studies dealing with the effects of spacing on growth (Rudolf 1951, Guilkey and Westing 1956, Wilde *et al.* 1968).

At age 6, dbh's of our plantings were comparable to dbh's of 10-year-old jack pine stands in lower Michigan (Rudolf 1951); and at age 7, the average dbh of our 24- by 24-in. planting (2.96 cm) was greater than the dbh of a Michigan 18- by 18-in. planting at 15 years (Guilkey and Westing 1956). At age 10, the dbh of our 24- by 24-in. planting will probably surpass the average dbh (4.6 cm) of 15-year-old jack pine planted at 18- by 18- and 24- by 24-in. in Wisconsin (Wilde *et al.* 1968) or Michigan (Guilkey and Westing 1956).

Spacing and Tree Slenderness

One important tree characteristic that depends both on height and diameter is the slenderness ratio or taper (Assmann 1970). Rudolf (1951) showed that the slenderness index (height in feet divided by dbh in inches) of 10-year-old jack pine trees decreased with increasing spacing from 11.5 in a 18- by 18-in. spacing to 6.5 in a 9- by 9-ft. spacing. The slenderness index in our study followed the same trend and at age 7 was 14.8, 13.5, and 9.9 in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively. The trend remained the same for the dominant trees but values for the same spacings were lower — 11.8, 11.6, and 9.1—which indicates that the dominant trees tapered more rapidly. In traditional forestry a low slenderness index is undesirable (Assmann 1970), but it is difficult to assign a significance to the slenderness ratio in the SRIC system.

Spacing and Survival

Survival increased with increasing spacing (tables 1 and 2). About 49, 68, and 94 percent of plants were still alive at age 7 in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively. During the 7th year the survival decreased by about 7 percent in the two denser plantings but remained the same in the 24- by 24-in. planting. At age 7, the survival in the 12- by 12- and 24- by 24-in. plantings was comparable to the survival of a 10-year-old jack pine plantation established at 18- by 18-in. spacing in lower Michigan (Rudolf 1951). However, the survival in the 24- by 24-in. planting was much higher than the survival in a 15-year-old jack pine plantation of the same spacing in Wisconsin (Wilde *et al.* 1968). The dbh and height of this 15-year-old plantation were reached at age 9 under the intensive culture system. If the two systems are comparable, more than 40 percent of the trees in our 7-year-old, 24- by 24-in. planting will die in the next 2 years—unless the irrigation and fertilization can compensate for the inadequate light.

Table 2.—*Jack pine survival per hectare*

Age	Spacing (inches)					
	9 by 9		12 by 12		24 by 24	
	Percent					
1	191,300	100	107,600	100	26,900	100
2	n.a.[1]	n.a.	n.a.	n.a.	26,900	100
3	n.a.	n.a.	n.a.	n.a.	26,900	100
4	160,900	84	104,600	97	26,900	100
5	142,700	75	101,600	94	26,900	100
6	106,800	56	80,500	75	25,200	94
7	93,700	49	73,500	68	25,200	94

[1] Not available.

We can only speculate on the reasons for mortality in our plantings. Inadequate light, soil moisture, and nutrients are frequently cited as the cause of death (Baker 1950, Kramer and Kozlowski 1960, Cooper 1961). In irrigated and fertilized plantations the inadequate light may be solely responsible for the death of the understory saplings. On a sunny day, light under canopies averaged only 27, 23, and 23 foot-candles in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively, which is below the photosynthetic compensation point.[1]

Spacing and Stand Structure

The main structural distinction between the stand spaced 9- by 9-in. and the one spaced 24- by 24-in. is the number of small understory trees in the denser planting. These trees may live for several years but their position under canopies and the small amount of light under canopies leave no doubt about their eventual fate. Heights of the dominant trees in all three spacings were about the same, but dominant tree density was higher in the two denser spacings. At age 6, the number of dominant trees was 259, 345, and 137 per 100 m^2 in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively. By age 7, the number of dominants had decreased by 22 and 25 in the 9- by 9- and 12- by 12-in. plantings, respectively, but had remained the same in the 24- by 24-in. planting. It appears that the number of dominant trees in the three spacings is converging. The same structural development trend was found by Sorensen (1968) in aspen stands.

Spacing and Weight of Individual Trees

The average tree weight as well as weights of all tree components—stems, branches, and needles—increased with increasing spacing. At age 7, the average weight of whole trees was 510, 770, and 2,100 g in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively.

At age 4, our seedlings were 3 to 12 times heavier than jack pine of the same age grown at wider spacings (Logan 1966). Our plants averaged 166, 240, and 606 g at 4 years and 420, 610, and 1,690 g at 6 years in the 9- by 9-, 12- by 12-, and 24- by 24-in. spacings, respectively.

Dry weight distribution among tree components of Logan's 6-year-old plants indicated their open-grown condition and their more juvenile character in comparison to our plants. Stems, branches, and needles accounted, respectively, for 28, 29, and 43 percent of the above-ground biomass in Logan's plants and for 40, 30, and 30 percent in our 24- by 24-in. planting and 54, 22, and 24 percent in our 9- by 9-in. planting (Zavitkovski and Dawson 1977).

[1] *Zavitkovski, J. Unpublished data on file at the Institute of Forest Genetics, Rhinelander, Wisconsin.*

Spacing and Biomass Growth Models

An allometric model (based on dbh) was used to calculate stand biomasses. Graphed data revealed no difference in relations between dbh and dry weight of tree components from the 9- by 9- and 12- by 12-in. plantings so their data were pooled; the relations were different for trees from the 24- by 24-in. so their data were handled separately. The 1975 and 1976 data within each spacing were also pooled because no significant differences were found between regression coefficients (table 3).

The variance of dry weight was low in regressions between dbh and whole tree and stem biomass but it was high for branches and needles (table 3). The test of additivity of biomass (i.e., comparing, for a given dbh, the whole tree biomass with the sum of stem, branch, and needle biomasses) was excellent for regressions from the 9- by 9- and 12- by 12-in. plantings (less than 1 percent difference) and good for regressions from the 24- by 24-in. planting (less than 2 percent difference).

The regressions indicated that trees with the same dbh from the 24- by 24-in. planting had a greater branch and needle biomass for the entire range of dbh values, a greater total biomass for most of the dbh range and a greater stem biomass for trees with a dbh larger than 19 mm, than trees from the 9- by 9- and 12- by 12-in. plantings.

The regressions for the 6- and 7-year-old trees are not strictly comparable with regressions for older jack pine trees. Slopes of our regressions for trees from the 24- by 24-in. planting paralleled slopes of regressions presented by Crow (1971) for 50-year-old jack pine in Minnesota, by Hegyi (1972) for 11- to 65-year-old jack pine in northern Ontario, and by Doucet *et al.* (1976) for 41- to 46-year-old jack pine in Quebec. However, for the same dbh within the overlapping parts of the regressions, our trees and individual tree components were heavier. The difference was particularly great for branches and needles. Our regressions for trees from the 9- by 9- and 12- by 12-in. plantings had different slopes and could not be compared with other data.

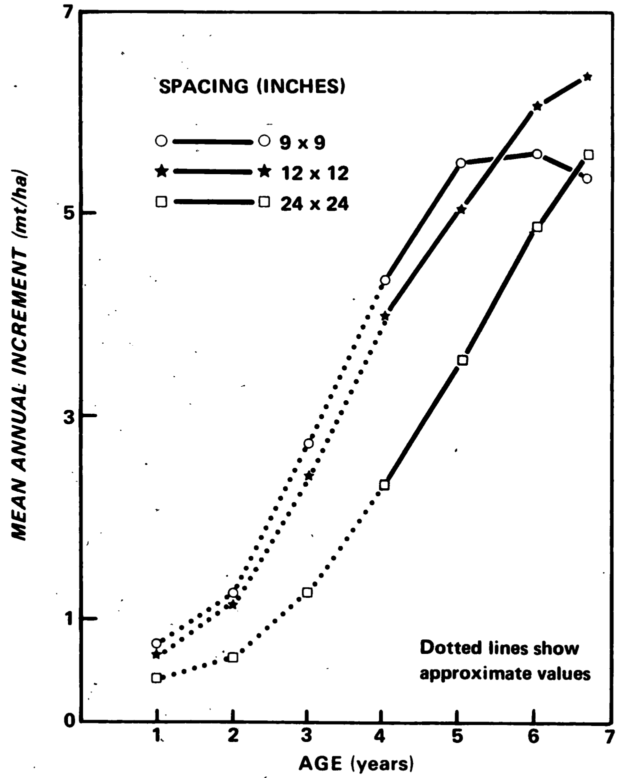

Figure 4.—*Mean annual increment of stems and branches in 1- to 7-year-old jack pine at three spacings.*

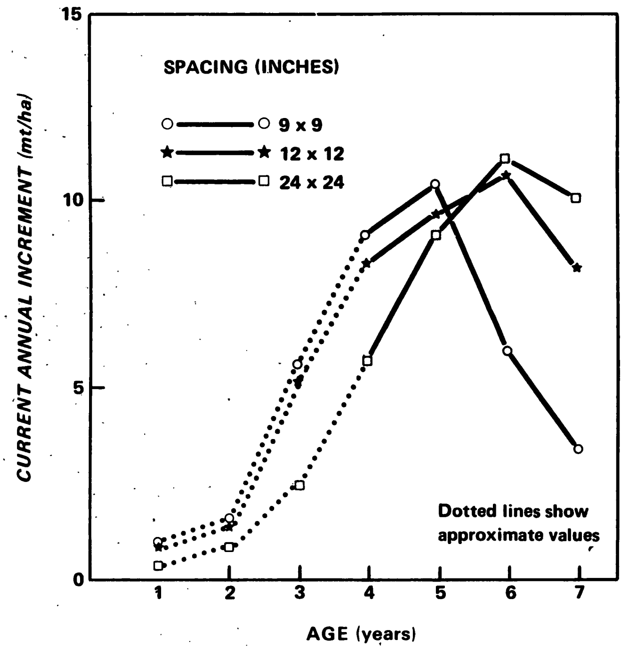

Figure 5.—*Current annual increment of stems and branches in 1- to 7-year-old jack pine at three spacings.*

Table 4.—*Mean annual increment and production*

(In mt/ha)

Age	Mean Annual Increment: 9 by 9	Mean Annual Increment: 12 by 12	Mean Annual Increment: 24 by 24	Mean Annual Production: 9 by 9	Mean Annual Production: 12 by 12	Mean Annual Production: 24 by 24
TOTAL BIOMASS						
4	7.0	6.4	4.1			
5	7.7	7.4	5.6	7.8	7.4	5.6
6	7.5	8.1	7.1	8.0	8.5	7.2
7	6.8	8.1	7.6	7.4	8.5	7.7
STEM AND BRANCH BIOMASS						
4	4.3	4.0	2.4			
5	5.6	5.1	3.7	5.7	5.1	3.7
6	5.7	6.1	4.9	6.2	6.5	5.0
7	5.4	6.3	5.6	6.0	6.7	5.7

systems are not strictly comparable. However, in areas with adequate irrigation water and high demand for fiber (e.g., the Lake States), the SRIC system may allow the land owner to produce as much or more than can be produced in the southern and western parts of the United States. This point becomes even more pertinent when we consider the most productive species such as various *Populus* hybrids. Although the production in SRIC jack pine plantings was high, it was only half of what can be produced in SRIC *Populus* 'Tristis #1' plantings (Ek and Dawson 1976).

Stems

Through age 5, stem biomasses decreased with increased spacing (figs. 3 and 6). A reversal occurred at age 6, when the stem biomass of the 12- by 12-in. planting became the highest and remained so through age 7. Stem wood accounted for 78, 80, and 83 percent of the stem weight at the three spacings (table 6). The percentage in the 24- by 24-in. planting was significantly higher than in the 9- by 9-in. planting.

The m.a.i. of stem wood at age 7 was 3.1, 3.7, and 3.0 mt/ha/year as compared to 3.2, 3.4, and 2.3 mt/ha/year at age 6 in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively. It appears that the m.a.i. of stem wood in the 9- by 9-in. planting culminated at age 6 but it was steadily increasing in the two wider spacings. The sharp increase in the 24- by 24-in. planting suggests that the m.a.i. of stem wood (like that of other components) may eventually become the largest. The m.a.i. of stem wood in a 41- to 46-year-old jack pine stand in Quebec (Doucet *et al.* 1976) was 1.4 to 1.8 mt/ha/year and in an 11- to 20-year-old jack pine stand in Ontario it was 1.6 mt/ha/year (Hegyi 1972). The m.a.i. of stem wood of 4-year-old SRIC *Populus* 'Tristis # 1' was more than 10 mt/ha/year (Ek and Dawson 1976).

Table 5.—*Above-ground mean annual increment in selected forest plantations*

Species	Location	Age	M.a.i.	Reference
		Yrs.	*Mt/ha*	
Pinus banksiana	N. Wisconsin	7	8.1	Present study, 12- by 12-in.
P. banksiana	N. Ontario	11-65	1.2-3.4	Hegyi 1972
P. banksiana	Quebec	41-46	1.4-2.5	Doucet *et al.* 1976
P. banksiana	N.E. New Brunswick	29-57	0.9-2.8	MacLean and Wein 1976
P. densiflora	Japan	20-25	6.9	Ogasawara 1971
P. elliottii	N. Carolina	8	4.0	Nemeth 1973
P. radiata	Australia	12	9.9	Forrest and Ovington 1970
P. strobus	N. Carolina	15	4.6	Swank and Schreuder 1973
P. sylvestris	United Kingdom	35	4.7	Ovington 1957
P. taeda	N. Carolina	12	9.0	Nemeth 1973
P. taeda	S. Carolina	14	6.2	Harms and Langdon 1976
P. virginiana	Virginia	17	4.8	Madgwick 1968
Pseudotsuga menziesii	Washington	36	5.7	Cole *et al.* 1967
Tsuga heterophylla	W. Oregon	26	7.4	Fujimori 1971

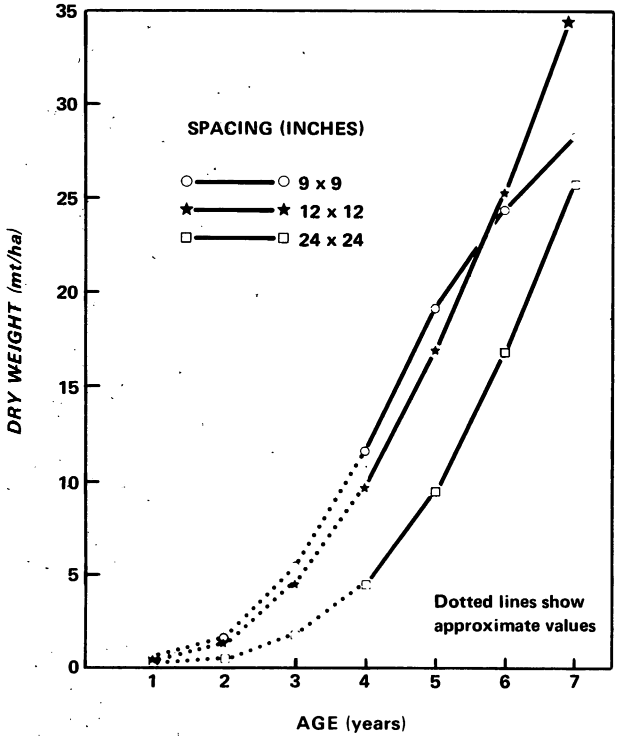

Figure 6.—*Stem biomass of 1- to 7-year-old jack pine at three spacings.*

Table 6.—*Biomass distribution among tree components in 7-year-old jack pine*

(In percent)

Spacing	Stem	Total tree			Stem		Branches	
		Branches	Needles	Other[1]	Wood	Bark	Wood	Bark
Inches								
9 x 9	59[a2]	19[a]	21[a]	1[a]	78[a]	22[a]	60[a]	40[a]
12 x 12	56[b]	22[b]	21[a]	1[a]	80[ab]	20[ab]	60[a]	40[a]
24 x 24	48[c]	26[c]	24[b]	1[a]	83[b]	17[b]	75[b]	25[b]

[1]Cones, buds, etc.

[2]Values (in columns) followed by the same letter are not significantly different (p=0.05).

Branches

During the first 5 years, branch biomass was similar in all three spacings (fig. 7). A separation occurred at age 6 when the branch biomass increased with increasing spacing. The pattern was the same at age 7 and is likely to remain so in future years. At age 7, branches accounted for 19, 22, and 26 percent of the total biomass in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively (table 6). Dead branches made up about 30 percent of the total branch biomass in the 9- by 9-, and 24- by 24-in. plantings and about 43 percent in the 12- by 12-in. planting (table 7). Stem and branch wood, the two most important components for fiber production, averaged 27.4, 33.1, and 31.7 mt/ha at age 7 in the 9- by 9-, 12- by 12-, and 24- by 24-in. plantings, respectively (table 1). The stem and branch biomass from age 6 to age 7 increased by only 2.5 mt/ha in the 9- by 9-in. planting but increased by 6.1 and 9.4 mt/ha in the 12- by 12- and 24- by 24-in. plantings. The increase in the 24- by 24-in. planting is consistent with the general trend, which indicates that in future years the 24- by 24-in. planting will be the most advantageous for fiber production.

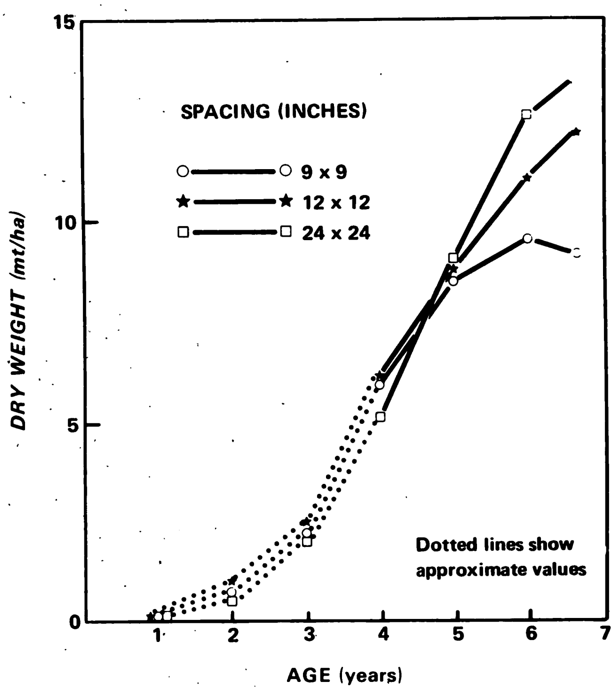

Figure 7.—*Branch biomass of 1- to 7-year-old jack pine at three spacings.*

Table 7.—*Branch and needle biomass distribution in 7-year-old jack pine*

(In percent)

Spacing	Branches: Current	Branches: Older	Branches: Dead	Needles: Current	Needles: Older	Needles: Dead
Inches						
9 x 9	[1]18[a]	50[ab]	32[a]	43[a]	54[a]	3[a]
12 x 12	17[a]	40[a]	43[a]	46[a]	48[ab]	6[ab]
24 x 24	16[a]	54[b]	30[a]	43[a]	46[b]	11[b]

[1]Values followed by the same letter are not significantly different (p=0.05).

For comparison, the percentage of branch weight in the 41- to 46-year-old jack pine in Quebec decreased with density from about 19 percent in open stands to about 16 percent in dense stands (Doucet *et al.* 1976). In that study, branch percentages were affected by site quality —they reached 20 percent of the total biomass on medium sites and 15 percent on good sites. The implication for intensive culture is that by manipulating site quality—fertilizing and irrigating—the percentage of biomass in branches may be regulated.

Bark

Bark percentages of stems and branches decreased with increased spacing and age (table 8). Stem bark accounted for from 17 to 29 percent of the stem, and branch bark accounted for from 25 to 56 percent of the branch weight. Branch bark dry weights per hectare remained about the same at ages 6 and 7 and stem bark increased by more than 1 mt/ha in that 1 year (table 1) (Zavitkovski and Dawson 1977).

Table 8.—*Bark percentages on stems and branches*

(In percent)

Age	Stems: 9 by 9	Stems: 12 by 12	Stems: 24 by 24	Branches: 9 by 9	Branches: 12 by 12	Branches: 24 by 24
4	29[a1]	23[b]	20[b]	56[a]	49[b]	37[c]
5	24[a]	20[b]	n.a.[2]	n.a.	n.a.	n.a.
6	19[a]	20[a]	18[a]	45[a]	39[a]	33[a]
7	22[a]	20[ab]	17[b]	40[a]	40[a]	25[b]

[1]Values with the same letter in each row are not significantly different (p=0.05).
[2]Not available.

Stem bark percentages ranged from 9 to 11 percent in 41- to 46-year-old jack pine in Quebec (Doucet *et al.* 1976), about 10 percent in 11- to 65-year-old jack pine in northern Ontario (Hegyi 1972), and about 15 percent on stems of 50-year-old jack pine in Minnesota (Crow 1971). We found no information on jack pine branch bark in the literature.

Needles

Needle biomass increased rapidly during the first 4 to 6 years and then leveled off between 10 and 13 mt/ha (fig. 8). At age 7, living needles accounted for 88 to 97 percent of the total needle weight (table 7) and averaged from 9.6 to 11.4 mt/ha (table 9). Needle weight increased with spacing and also with the biomass of branches (figs. 7 and 8). The data indicate that the upper limit of living needle weight is less than 12 mt/ha. It appears unlikely that a higher needle biomass could develop in stands that allow less than 1 percent of the sunlight to reach the ground.

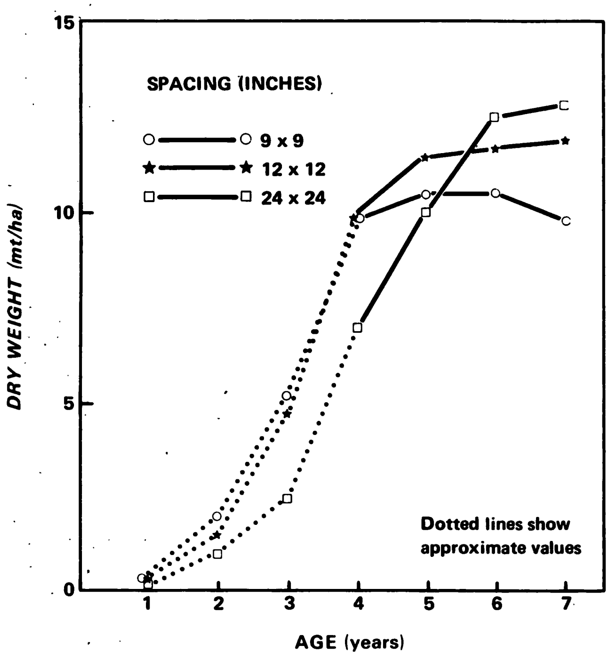

Figure 8.—*Needle biomass (including attached dead needles) in 1- to 7-year-old jack pine at three spacings.*

Table 9.—*Living needle biomass*

(In mt/he)

Age	All living needles: 9 by 9	12 by 12	24 by 24	Current year's needles: 9 by 9	12 by 12	24 by 24
4	8.9	8.9	6.1	n.a.[1]	n.a.	n.a.
5	9.4	10.2	9.0	n.a.	n.a.	n.a.
6	8.3	10.6	11.1	5.4	6.2	6.3
7	9.6	11.3	11.4	4.3	5.5	5.5

[1]Not available.

The percentage of total above-ground weight accounted for by needles increased with spacing and decreased with age (table 10). At age 7, needles made up about 21 percent of the total biomass in the two dense plantings and 24 percent in the 24- by 24-in. planting. Current year's needles accounted for 65, 58, and 57 percent of the living needles at age 6 and for 45, 49, and 48 percent at age 7 in plantings spaced at 9- by 9-, 12- by 12-, and 24- by 24-in., respectively. The steep decrease in the percentage of current needles in the 9- by 9-in. planting is evidence of increased competition, which was also responsible for a decrease in the c.a.i. and m.a.i. of stems and branches (figs. 4 and 5).

Needle biomasses of our stands were substantially higher than in jack pine stands tended in the traditional way. In 41- to 46-year-old jack pine in Quebec, needle biomass ranged from 3.45 to 7.79 mt/ha and needles accounted for from 4 to 9 percent of the above-ground biomass (Doucet *et al.* 1976). Needles made up about 9 percent of the

Table 10.—*Needles as percentages of total biomass*

(In percent)

Age	Spacings (inches): 9 by 9	12 by 12	24 by 24
4	37	38	45
5	30	32	44
6	23	24	29
7	21	21	24

above-ground biomass in 11- to 65-year-old jack pine in northern Ontario (Hegyi 1972). Biomass regressions in that study indicate that the percentage was higher for younger and smaller trees (about 18 percent for trees 3.0 cm in d.b.h.) than for older and larger trees (about 4 percent for trees 30 cm in d.b.h.). In 50-year-old jack pine in Minnesota (Crow 1971), needles made up about 8 percent of the above-ground biomass and appeared to increase as the tree size increased.

Needle dry weights in the Quebec stands were substantially higher on the medium than on the good sites (Doucet *et al.* 1976). This contradicted trends reported by others who found either a strong positive relation between site quality and needle biomass (Burger 1953, Hutnik 1964, Satoo 1967a), a slight positive relation (Satoo 1967b), or no relation (Moller 1945). This question is important for the concept of intensive culture because fertilization and irrigation increase site quality and foliage biomasses. Doucet *et al.* suggested that the generally longer crowns in stands on the medium sites were probably responsible for the higher foliage biomasses on those sites. More importantly, however, they observed that the total net annual weight increment for the previous 5 years was higher on the medium than on the good site. Although that is encouraging for the intensive culture system, it doesn't explain the sudden reversal in productivity during the last 5 years.

We found a positive relation between living needle biomass and c.a.p. of stems and branches for ages 4, 5, and 6 (fig. 9) but the 7th year data fell below this block of data. Perhaps the inadequate irrigation in 1976 reduced stem and branch c.a.p. below that expected from the regression. If this explanation is correct, then not only the production of stems and branches but also that of current year's foliage would be affected and a relation between current year's foliage biomass and the c.a.p. of stems and branches would show no deviation from linearity, even for the droughty 1976. Unfortunately, the information on current year's foliage biomass is only available for the 1975 and 1976 season (table 9). However, the relation was good, the current year's foliage biomass accounted for 93 percent of the variation in the c.a.p. of stems and branches, and the data showed no separation (fig. 10).

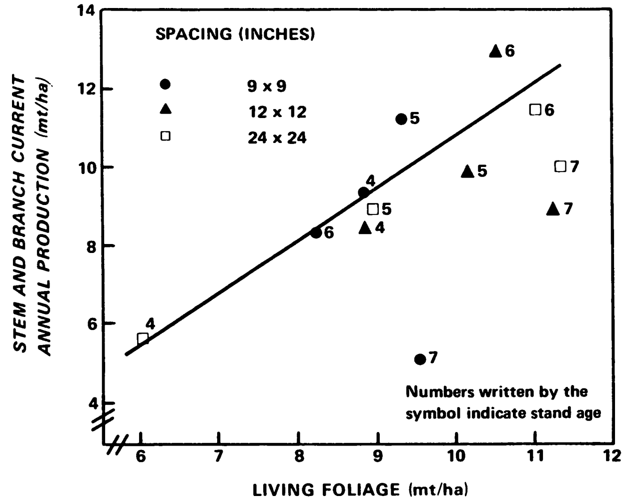

Figure 9.—*Relation between living needle biomass and current annual production of stems and branches in 4- to 7-year-old jack pine at three spacings. Regression for the 4- to 6-year-old stands:* $Y = -2.32 + 1.29x$; ($R^2 = 0.81$; $S_{y.x} = 0.98$).

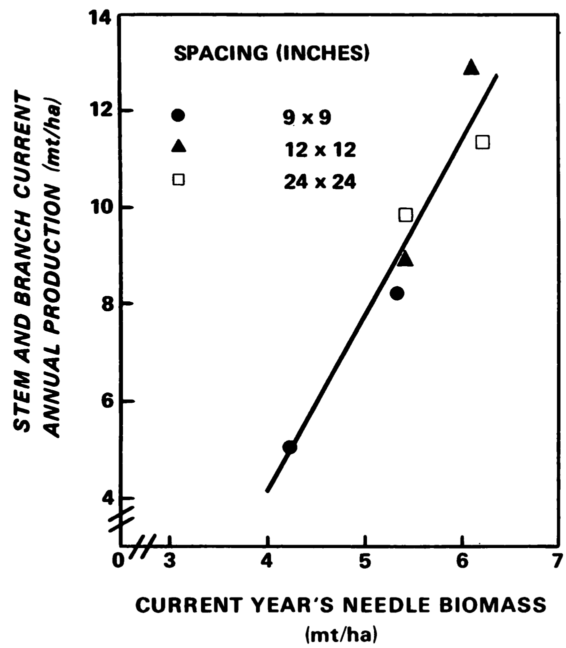

Figure 10.—*Relation between current year's foliage and current annual production of stems and branches in 6- and 7-year-old jack pine at three spacings. Regression* $Y = -10.6 + 3.62x$; ($R^2 = 0.93$; $S_{y.x} = 0.81$).

APPLICATION OF SRIC SYSTEM TO JACK PINE

Results of our studies indicate how the system could be applied, what could be improved to further increase the production, and what yields can be achieved under good growth conditions. These preliminary results were obtained in small sample plots and will have to be confirmed in larger experimental plantations. In spite of the uncertainties about the exact production, the findings indicate that the SRIC system will strikingly increase biomass production in comparison to that achieved in traditional silvicultural systems.

Plantation Establishment

The use of plastic tube containers, at least of the type used in our studies, should be avoided. Height growth of our seedlings was drastically reduced during the first 2 years compared to other seedlings. Other types of containers that may further speed up growth and reduce losses are being tested.

Effects on Irrigation

Although determining an optimum level of soil nutrients and soil moisture were not objectives of our studies, the reduced irrigation during the 1976 droughty growing season showed how important soil moisture is for forest production. We have not determined the optimum irrigation amount or schedule, but studies are in progress to evaluate effects of both irrigation and nutrients on growth of forest plantations (Hansen 1976).

Spacing and Rotation

One of the objectives of our study was to find the optimum combination of spacing and rotation with respect to biomass production. The optimum rotation depends on spacing and, in general, is shorter for dense plantings. In this study, the optimum biological rotation for the 9- by 9-in. planting would be 6 years because it was then that the m.a.p. of stems and branches peaked (table 4). For the 12- by 12-in. planting the optimum rotation would be 7 years because it was then that the m.a.p. peaked. The optimum rotation in the 24- by 24-in. planting was not reached during the 7 years but the shape of the curve for the m.a.p. of stems and branches indicates that it will be reached in about 2 years and may be higher than in either of the denser plantings. Similar relations can be seen in Ek and Dawson's (1976) data for intensively-cultured *Populus* 'Tristis #1'.

Biomass Allocation and Wood Quality

The quality of the wood is beyond the scope of this study. However, biomass distribution among tree components was affected by spacing and that may affect the suitability of the material for various industrial purposes. Percentages of both branches and needles increased (and would tend to reduce the quality) and percentages of stem and branch bark decreased (and would tend to increase the quality of material) with increasing spacing. Moreover, the average size and number of harvested trees will be strongly affected by spacing and may require different types of harvesting equipment.

Jack pine was included in our intensive culture studies because it is widely used by the pulp and paper industry—mature jack pine fibers are long and suitable for industrial purposes. However, Crist *et al.* (1977) have shown that the fiber quality of juvenile jack pine is lower than that of mature trees and does not appreciably differ from that of *Populus* 'Tristis #1' whose m.a.i. of stems and branches under SRIC systems is at least two times higher than the m.a.i. of jack pine.

Role of Canopies in Production

The positive and significant relation between living needle biomass and the c.a.p. of stems and branches illustrates the importance of forest canopies for maximizing forest production. The quantity of foliage can be manipulated by fertilization and irrigation. Still unknown is the optimum foliage biomass, which is as important in forest production as the optimum leaf area index is in agronomy. The importance of optimizing foliage biomass is illustrated by the following example for red alder (Zavitkovski *et al.* 1974): maximum annual production was reached in stands with a leaf biomass of about 5.5 mt/ha—at higher foliage biomasses, production of stems and branches was reduced from about 14 mt/ha/year to about 10 mt/ha/year. It was not possible to estimate the optimum leaf biomass in our jack pine plantings and, it would be unwarranted to attach any significance to the lower production observed in the 24- by 24-in. planting that had the maximum foliage biomass of 11.4 mt/ha at age 6 (fig. 9).

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Spacing and rotation length effects were studied for 7 years in intensively cultured jack pine stands. Production culminated at age 5 in the densest planting and progressively later in more open spacing. Biomass production was two to several times higher than in jack pine plantations grown under traditional silvicultural systems.

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