forest management note

Note No. 39 Northern Forestry Centre Edmonton, Alberta

SPACING EFFECTS 20 YEARS AFTER PLANTING THREE CONIFERS IN MANITOBA

As reforestation by planting increases across Canada, quantitative information is required on how initial spacing affects subsequent stand development and yield and what spacings should be used to achieve certain timber yield and value objectives. A spacing study of three native conifers, jack pine (*Pinus banksiana* Lamb.), red pine (*P. resinosa* Ait.), and white spruce (*Picea glauca* (Moench) Voss), was started in 1963 in southeastern Manitoba. Results to 15 years were reported by Bella and De Franceschi (1980); this Note provides the latest growth information and covers the first 20 years after planting.

STUDY AREA AND METHODS

The study area is located at Moodie, Manitoba, on flat, sandy, nutritionally poor soils with a fresh moisture regime and is in the Rainy River Section (L.12) of the Great Lakes-St. Lawrence Forest Region (Rowe 1972). The planting site was an abandoned field with grasses and low shrubs. Furrows were ploughed to prepare the ground for planting.

Three-year-old stock was planted in May 1963 using the slit method at spacings of 1.2, 1.8, 2.4, and 3.0 m in plots of 11 × 11 trees. Each spacing was replicated four times per species. During the first measurement in 1973, plots with heavy mortality resulting from an extreme drought in the summer of 1967 were abandoned. These were two jack pine and two red pine plots at 1.8-m spacing and two red pine plots at 2.4-m spacing.

Measurements included a diameter at breast height (dbh) tally of all living trees and the height and crown width of 10–20 trees per plot covering a range of sizes (Table 1). Growth analysis was based on trees with complete surround, and all border trees were excluded.

RESULTS AND DISCUSSION

Although the prime objective of spacing control is to enhance merchantable volume production, it is too early to express the present results in volume terms. In analyzing spacing effects, therefore, emphasis was on readily observable components of volume (e.g., number of trees, diameter, and height) for both the 250 largest diameter trees per hectare and the total stand. Total and merchantable volumes, however, are also presented.

Number of Trees and Mortality

The number of trees planted in 1963 ranged from 6727 down to 1075 per hectare, at spacings ranging from 1.2 to 3.0 m. Twenty years later the numbers for the 1.2-m spacing ranged from 4600 per hectare for red pine to 5800 per hectare for white spruce, a reduction of 15-30% (Fig. 1). For the two pine species, recent mortality has occurred mainly among the smaller trees and has declined with increasing tree size and wider spacing. Similar trends in mortality have not yet emerged for spruce, which had virtually no mortality during the last 5-year period.

These results suggest that most of the mortality in pines, which have reached full crown closure even at the widest spacings, arises from crowding and suppression. In contrast, spruce, with much smaller trees and incomplete crown closure, is still virtually free-growing and has had no suppression mortality.

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Table 1. Plot summaries of trees with complete surround, 1978 and 1983

Species and spacing	No. of plots	Diameter at breast height (cm)								Height (m)								Crown width (m)							
		1978				1983				1978				1983				1978				1983			
		No. of trees	Avg.	Min.	Max.	No. of trees	Avg.	Min.	Max.	No. of trees	Avg.	Min.	Max.	No. of trees	Avg.	Min.	Max.	No. of trees	Avg.	Min.	Max.	No. of trees	Avg.	Min.	Max.
Jack pine																									
1.2	4	143	6.0	1.0	10.7	84	7.4	2.5	12.4	42	5.6	4.3	7.5	22	8.0	5.8	10.1	0	—[a]	—	—	22	1.9	1.1	2.9
1.8	2	77	7.9	1.8	13.7	65	9.8	3.0	14.7	25	5.8	3.8	7.1	23	8.3	3.6	9.8	0	—	—	—	23	2.3	0.9	3.2
2.4	4	179	9.5	1.0	15.7	161	11.7	2.8	19.8	67	5.5	2.4	7.3	57	8.2	5.3	10.3	67	3.2	0.6	6.1	57	2.9	1.4	4.6
3.0	4	194	8.7	0.8	13.2	182	11.8	1.8	16.8	64	4.7	2.9	6.3	58	6.9	1.7	10.0	64	3.5	1.6	5.0	58	3.5	0.2	4.9
Total or avg.		593	8.0	0.8	15.7	492	10.2	1.8	19.8	198	5.4	2.4	7.5	160	7.8	1.7	10.3	131	3.3	0.6	6.1	160	2.6	0.2	4.9
Red pine																									
1.2	4	171	5.7	0.0	10.7	98	7.9	1.8	13.7	56	4.1	0.5	5.9	31	6.4	4.1	8.3	0	—	—	—	31	1.9	1.5	2.4
1.8	2	87	7.2	0.0	13.2	67	11.1	1.5	18.0	37	4.3	0.3	5.8	26	7.1	4.8	9.0	35	2.2	0.6	3.4	26	2.7	1.7	4.1
2.4	2	92	9.8	1.5	14.0	92	14.2	2.0	19.6	41	5.1	3.4	6.3	38	8.0	6.5	9.6	38	3.0	1.7	4.0	38	3.3	2.1	4.3
3.0	4	242	9.3	1.0	15.7	226	14.0	2.5	21.3	77	4.7	2.6	6.1	76	7.3	3.8	9.1	77	2.8	1.5	4.1	76	3.5	2.0	5.2
Total or avg.		592	8.0	0.0	15.7	483	11.8	1.5	21.3	211	4.5	0.3	6.3	171	7.2	3.8	9.6	150	2.7	0.6	4.1	171	2.8	1.5	5.2
White spruce																									
1.2	4	195	0.6	0.0	4.3	194	2.0	0.0	7.1	195	1.3	0.3	2.8	136	1.7	0.4	4.4	0	—	—	—	38	1.3	0.3	2.0
1.8	4	186	0.8	0.0	4.3	186	2.8	0.0	9.1	186	1.5	0.4	3.5	109	1.9	0.7	4.8	0	—	—	—	38	1.6	0.5	2.4
2.4	4	307	2.3	0.0	7.1	302	5.4	0.0	13.0	307	2.2	0.5	4.7	92	2.8	0.6	6.7	0	—	—	—	61	2.2	0.6	3.0
3.0	4	262	1.6	0.0	5.1	256	4.9	0.0	11.9	262	1.8	0.4	3.2	105	2.4	0.5	4.6	0	—	—	—	50	1.9	0.3	2.9
Total or avg.		950	1.3	0.0	7.1	938	3.8	0.0	13.0	950	1.7	0.3	4.7	442	2.2	0.4	6.7	0	—	—	—	187	1.7	0.3	3.0

[a] Not applicable.

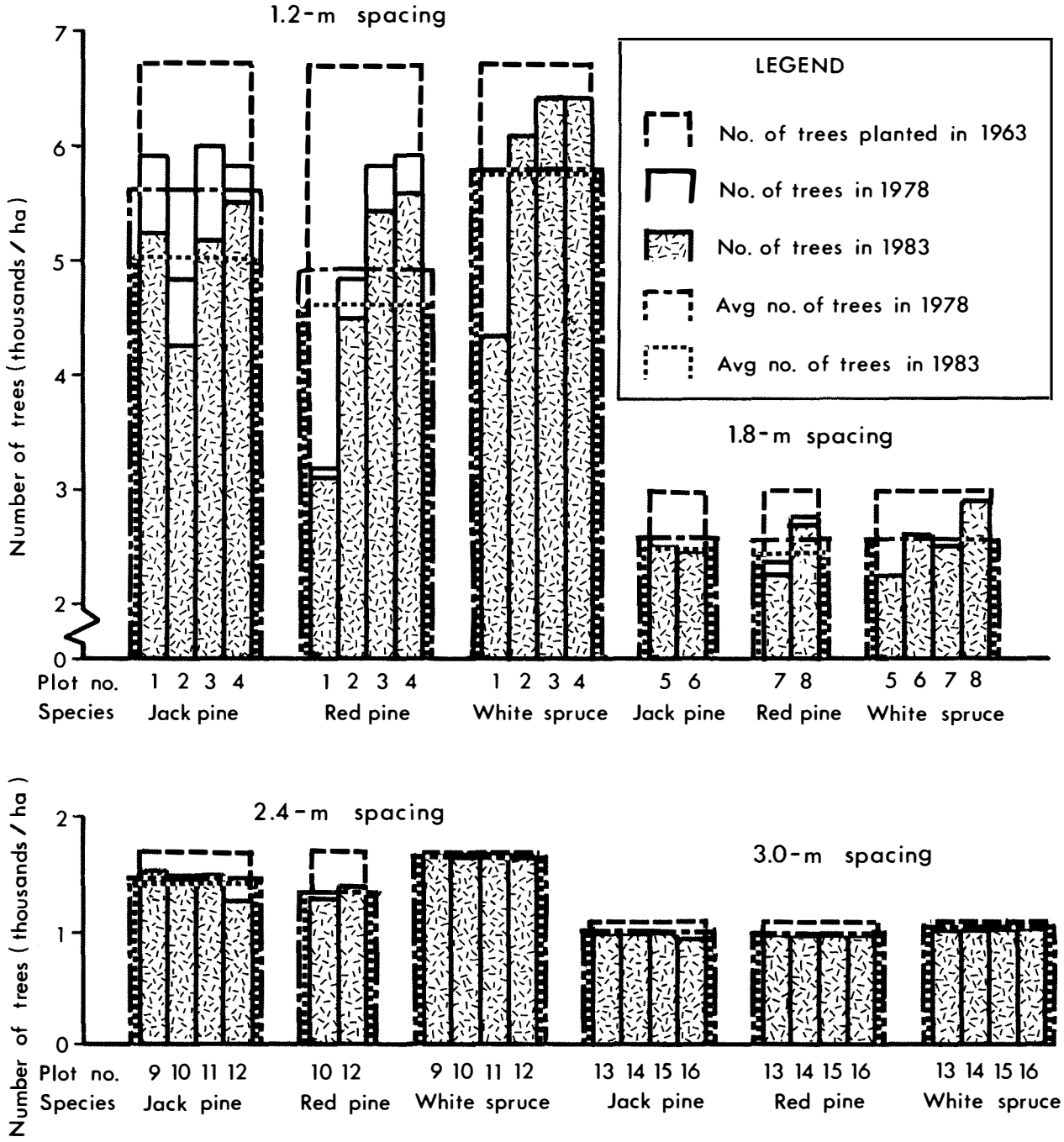

Figure 1. Number of trees planted in 1963 and number still living in 1978 and 1983.

Although most of the mortality seems to be suppression-related, there may be other agents contributing to the death of the trees. In jack pine, for example, 40% of the trees that have died in the last 5 years had some bark damage (chewing) from small mammals. A greater proportion of the jack pine mortality and most of the red pine mortality, however, were from unknown causes.

Diameter

Total stand

Average dbh for the two pine species ranged from 7.4 cm (for jack pine at 1.2-m spacing) to 14.2 cm (for red pine at 3.0-m spacing); red pine generally had somewhat larger diameters than jack pine. White spruce average dbh ranged from 2.0 to 5.4 cm (Table 1).

For all three species, average dbh generally increased with wider spacing, with jack and red pine showing the strongest trends in this direction. In jack pine, average dbh in 1983 was nearly 60% greater at 2.4-m spacing than at 1.2-m spacing (Table 1), but no further increase occurred at 3.0-m spacing. In red pine, the difference in average dbh between 1.2-m and 2.4-m spacings was even greater, almost 80%, with a slight decline at 3.0-m spacing. White spruce had over 100% difference in dbh between 1.2-m and 2.4-m spacings, but the trend was inconsistent and showed a small decline at 3.0 m.

Size distribution, especially the frequency of large trees, has a major impact on merchantable volume production. In 1983, red pine had many more large-diameter trees than did jack pine (Fig. 2). For example, there were three times as many red pine (600) as jack pine (200) that were 14 cm and larger at the 3-m spacing (points A and B in Fig. 2). These results also show optimum diameter growth at 2.4-m spacing for both pines.

The 250 largest trees per hectare

The two pines, especially red pine, showed a consistent increase (about 40%) in average dbh with increased spacing for the 250 largest trees/ha (Fig. 3). The range was from 10.7 cm at 1.2-m spacing to 14.8 cm at 2.4-m spacing for jack pine and from 11.8 cm at 1.2-m spacing to 17.3 cm at 2.4- and 3.0-m spacings for red pine. White spruce showed no consistent spacing effect, although dbh increased from 5.8 cm at 1.8-m spacing to 9.0 cm at 2.4-m spacing.

Up to 1978, the two pines had about the same average dbh in the 250 largest trees of each species (Fig. 3), but in the following 5 years red pine has grown almost twice as fast, surpassing jack pine.

Height

Total stand

In 1983, jack pine had the greatest average height at 7.8 m, compared to 7.2 m for red pine and 2.2 m for white spruce (Table 1). Average height increment for the last 5-year period, however, was greatest for red pine at 2.7 m, followed by jack pine at 2.4 m and white spruce at 0.5 m.

No consistent trend emerged in average height in relation to spacing, although the best growth for all three conifers generally occurred at the two intermediate spacings of 1.8 and 2.4 m. In 1983, jack pine at the widest spacing had a significantly ($p < 0.05$) lower average height (in excess of 1 m; Table 1) than it did at intermediate spacings.

The 250 largest trees per hectare

Jack pine reached approximately 9.0 m in height at 1.2-, 1.8-, and 2.4-m spacings; at 3.0-m spacing this average was about 1 m shorter (Fig. 4). Red pine averaged about 8 m and showed no consistent spacing effects, although the closest spacing had the shortest dominants and the widest spacing had the tallest (Fig. 4). This likely reflects the greater dbh at wider spacing and is an indication of fairly constant stem form across planting densities. White spruce averaged slightly over 4 m in height for the largest 250 trees/ha but showed no consistent spacing effect. The best height of 4.9 m occurred at the 2.4-m spacing, compared to a mean height of 3.7 m for each of the other three spacings.

Height-diameter Relationships

Spacing had a consistent effect on the height-dbh relationship in jack pine, where trees of equal dbh were about 1 m taller at narrow spacing than at wide spacing. No consistent trends emerged in height-dbh relationships for red pine and white spruce.[1] A comparison of height-dbh curves for the two pines showed that, on average,

[1] Analyses available from the author upon request.

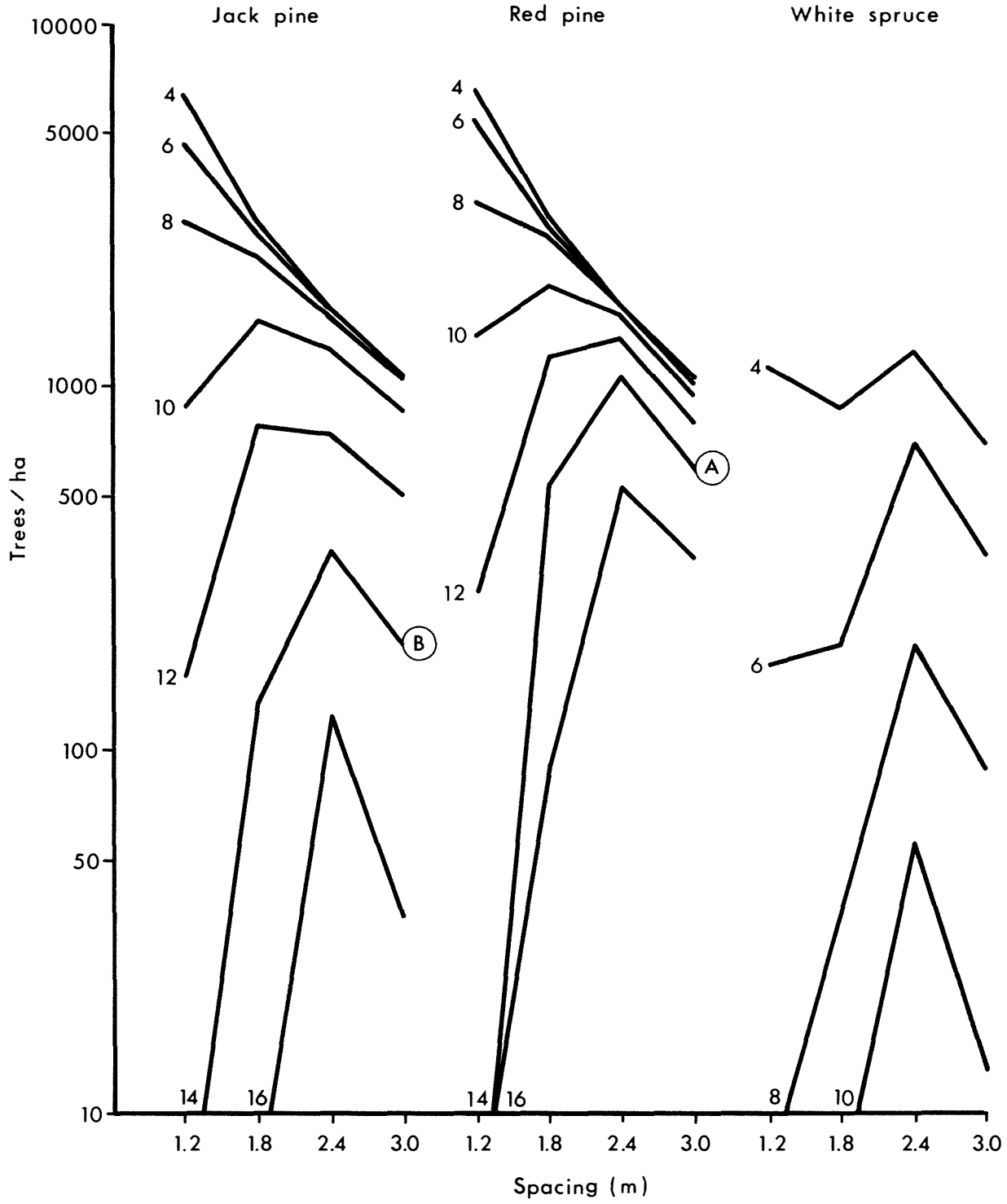

Figure 2. Number of trees/ha above a specified dbh (e.g., 4, 6, 8, 10, 12, and 14 cm), assuming a full complement of trees. For example, points A and B illustrate that there were three times as many red pine as jack pine that were 14 cm and larger at the 3.0-m spacing.

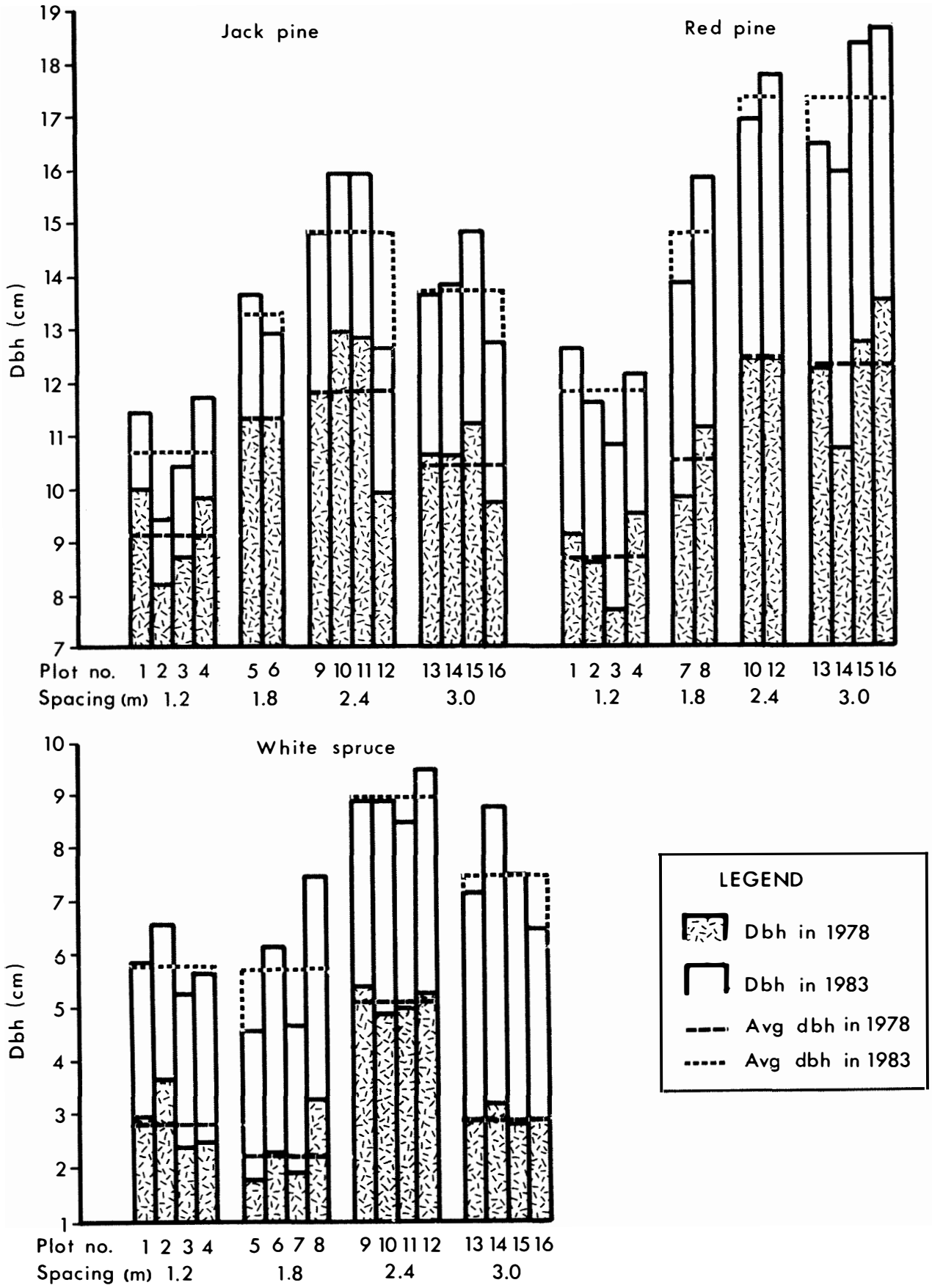

Figure 3. Average dbh of the largest 250 trees/ha.

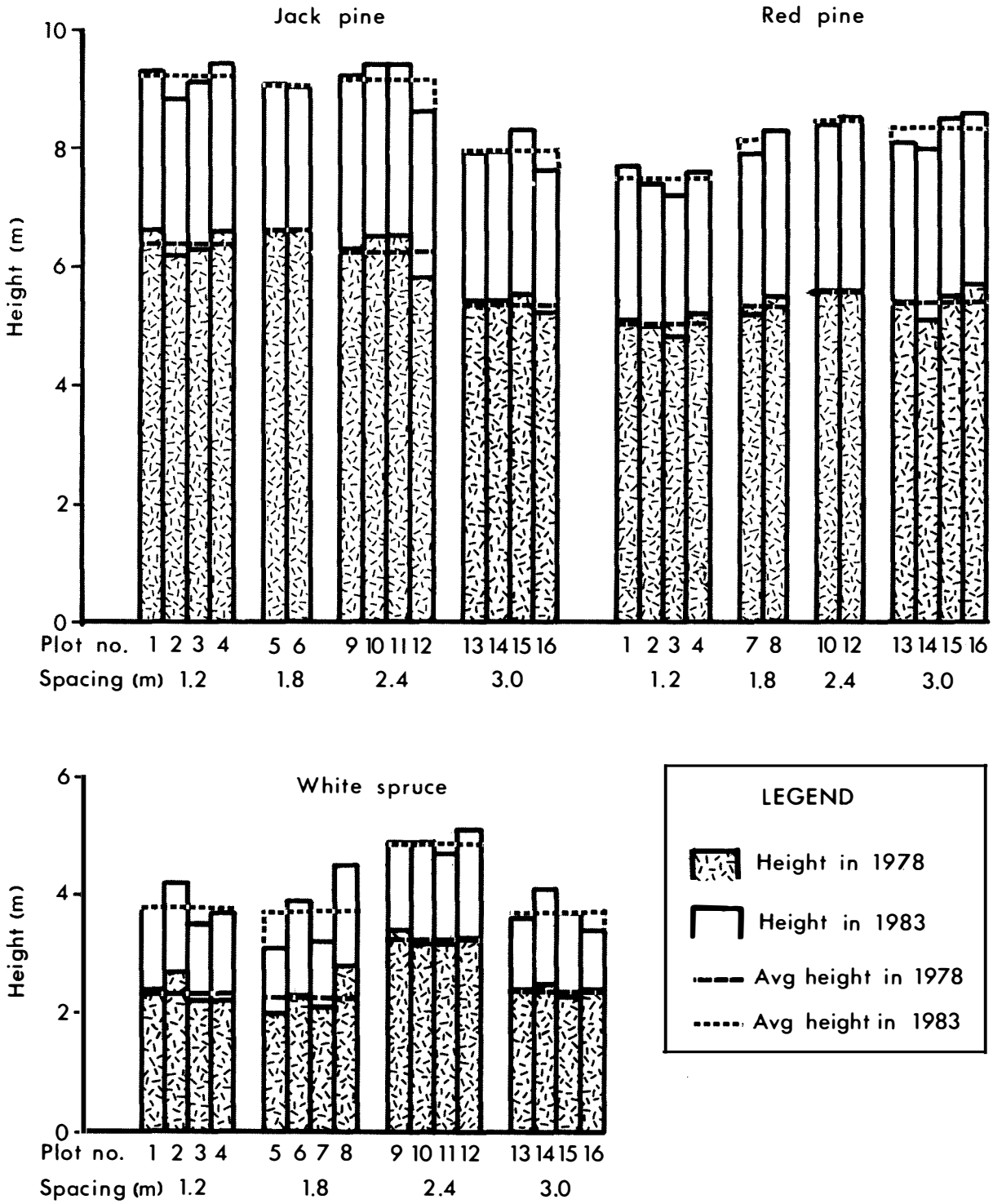

Figure 4. Average height of the largest 250 trees/ha.

jack pine trees were about 0.5 m taller than red pine trees of the same diameter.

Volume

Total stand volumes with a full complement of complete surround trees for the two pines were highest at the closest spacing and declined as spacing increased (Table 2). The same applied for jack pine when all living trees (actual volumes) in the inner plot (9 × 9 trees) were considered, but red pine had highest total volumes at intermediate spacings. The difference between the actual and potential full complement of tree volumes is a reflection of past and current tree mortality, the latter of which has accelerated at close spacing because of increased crowding. The highest total average tree volume occurred at the 2.4-m spacing (Table 2).

Merchantable volumes for the two pines were highest at the two intermediate spacings (1.8 and 2.4 m), where a large number of trees had reached merchantable size.

Total stand volumes were also highest at the closest spacing for spruce with a full complement of trees and at 2.4-m spacing for actual stand volumes. To date, this species has produced virtually no merchantable material.

Crown Width and Crown Closure

For all three conifers, crown width (CW) increased with spacing for trees of similar dbh, and this difference increased somewhat with greater dbh.[2] For jack pine, the CW-dbh relationship was about the same for spacings of 1.2, 1.8, and 2.4 m, but at the 3.0-m spacing the large trees (those above 12 cm dbh) had crowns up to 1 m wider than those at the three closer spacings. Excessively wide crowns mean heavy branches and greater taper (Fig. 5), which may reduce the future value of this timber. For red pine and white spruce, the increase in crown width with spacing was gradual and consistent, and the absolute difference in crown width between the two extremes was not as large as that for jack pine.

By 1983, both pines reached crown closure at all spacings, whereas white spruce reached closure only at the closest spacing (Fig. 6). Figure 6 indicates that in 1978, jack pine had greater average crown width and crowding than red pine, but by 1983 this trend was reversed for all but the widest spacing. This may be due at least in part to greater crown overlap arising from the somewhat more shade-tolerant growth habit of red pine.

The apparent decline in average crown width at wide spacing in 1978 for red pine and in 1983 for white spruce indicates a decline in average tree size at this spacing and a corresponding decline in crown width.

SUMMARY AND CONCLUSIONS

Red pine had the largest average dbh in terms of both total stand (11.8 cm in 1983) and the 250 largest trees/ha. Jack pine fell behind red pine by about 15% (10.2 cm). White spruce had dbh growth less than half that of the pines.

For the two pines, average dbh increased by 60-80% as spacing increased from 1.2 to 2.4 m. No further improvement occurred at the 3.0-m spacing. Similar trends emerged for average dbh of the 250 largest trees/ha, although the differences with spacing were only about 40%. As of yet, dbh growth of spruce has shown no consistent relationship with spacing.

Jack pine reached the best average height (7.8 m), followed by red pine (7.2 m) and white spruce (2.2 m). During the current 5 year period, red pine has slightly outgrown jack pine. Spacing had no consistent effect on height growth, although the best growth occurred at intermediate spacings and jack pine had a significant reduction of growth at the widest spacing.

Total stand volumes for the two pines with the full complement of complete surround trees were generally highest at the closest spacings, whereas merchantable volumes were highest at the two intermediate spacings, as were total volumes of all living trees in the inner plots. White spruce had negligible volumes at 20 years.

Crown width showed a gradual increase with spacing for all three conifers; for jack pine the increase in crown width was more pronounced and quite dramatic for large trees (above 12 cm dbh) at the widest spacing. This means heavy branches and greater taper.

These results suggest an optimum spacing of between 1.8 and 2.4 m for both pines in order to achieve rapid tree growth and high future timber yields. Unlike jack pine, red pine retains good tree form even at wide

[2] Analyses available from the author upon request.

Table 2. Tree and stand volume[1] by species and spacing, 1983

Species	Spacing (m)	Volume based on all living trees in the 9 × 9 inner plot matrix			Volume assuming a full complement of complete surround trees		
		Total (dm^3/tree)	Total (m^3/ha)	Merchantable (m^3/ha)	Total (dm^3/tree)	Total (m^3/ha)	Merchantable (m^3/ha)
Jack pine	1.2	22.1	111.5	42.8	19.6	131.7	42.0
	1.8	37.5	92.1	60.5	35.4	106.1	69.0
	2.4	50.3	72.2	55.8	48.1	81.0	61.4
	3.0	41.0	39.5	30.0	41.6	44.8	34.2
Red pine	1.2	20.5	91.7	38.6	19.3	129.9	54.0
	1.8	38.9	96.1	72.3	38.5	115.0	84.6
	2.4	67.8	96.2	83.8	67.5	113.6	99.0
	3.0	63.7	62.0	53.9	63.1	67.9	59.0
White spruce	1.2	1.2	4.1	0	1.4	9.9	0
	1.8	1.3	2.7	0	1.5	4.5	0
	2.4	5.2	8.3	1.0	5.2	8.7	1.1
	3.0	3.4	3.4	0.3	3.5	3.8	0.3

[1] Estimated using Honer's (1967) standard volume tables. For merchantable volume: stump, 15 cm; diameter at breast height outside bark, >9 cm; top diameter inside bark, 7 cm.

spacing. Both species have shown rapid growth, but it is too early to say with any confidence which species is superior. As expected, spruce grew at less than half the rate of the pines in the first 20 years after planting; therefore, spruce is not recommended for planting on similar sites.

I.E. Bella
October 1986

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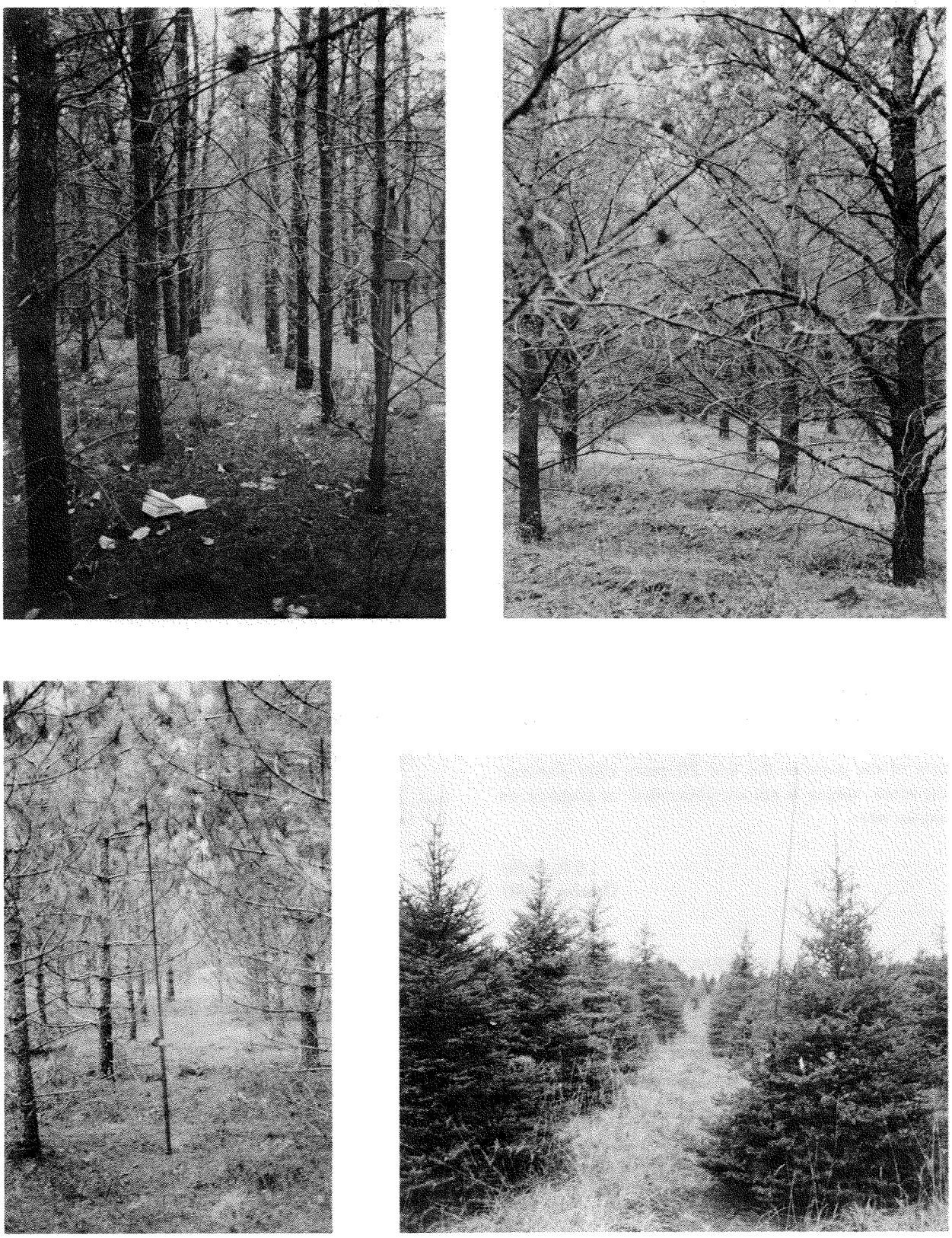

Figure 5. Jack pine, red pine, and white spruce at different spacing in 1985: (a, b) jack pine at 1.2 and 3.0 m; (c) red pine at 3.0 m; (d) white spruce at 2.4 m.

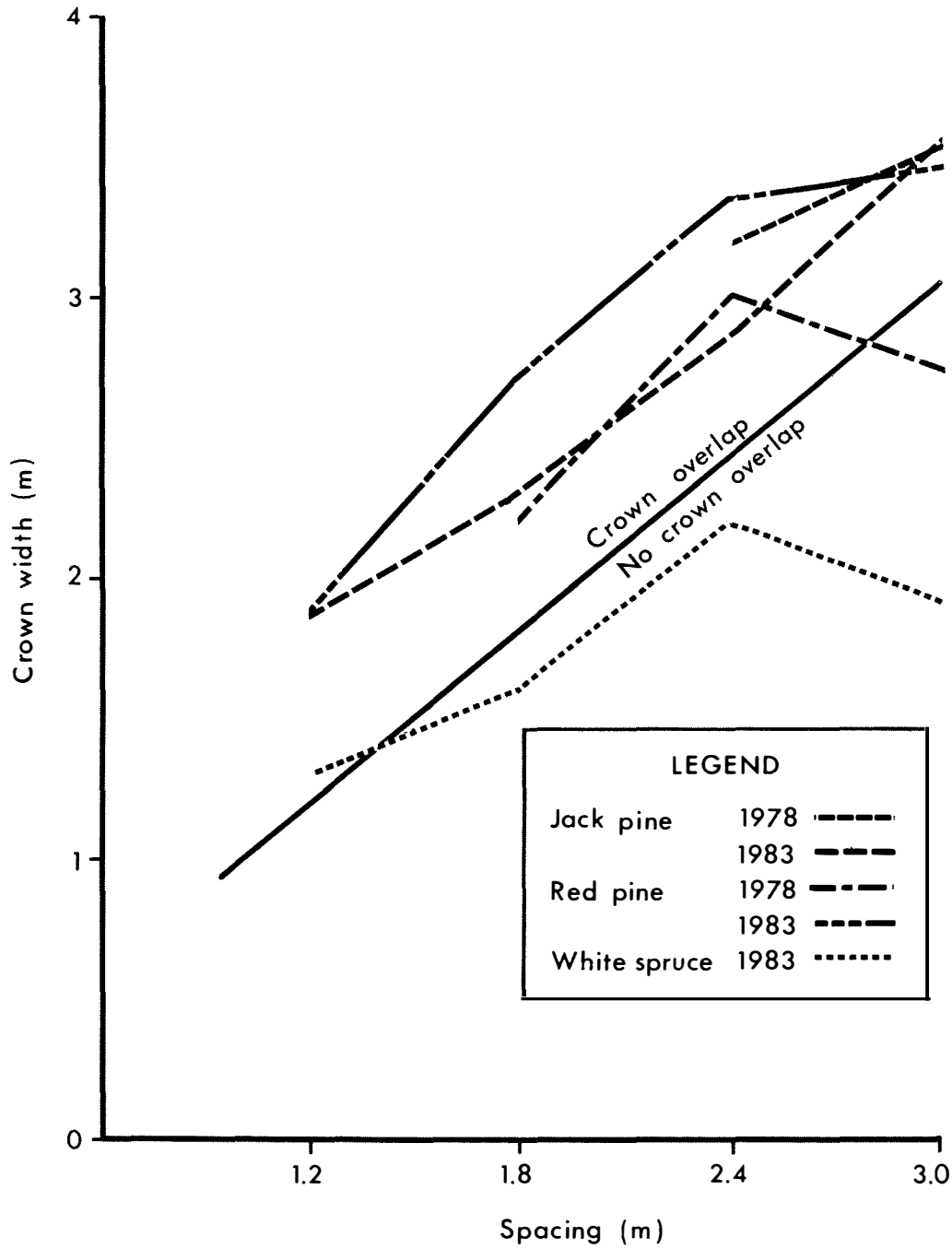

Figure 6. Average crown width in relation to spacing.

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