EFFECT OF TUBE DIAMETER AND SPACING ON THE SIZE OF TUBED SEEDLING PLANTING STOCK

J. B. SCARRATT

GREAT LAKES FOREST RESEARCH CENTRE
SAULT STE. MARIE, ONTARIO

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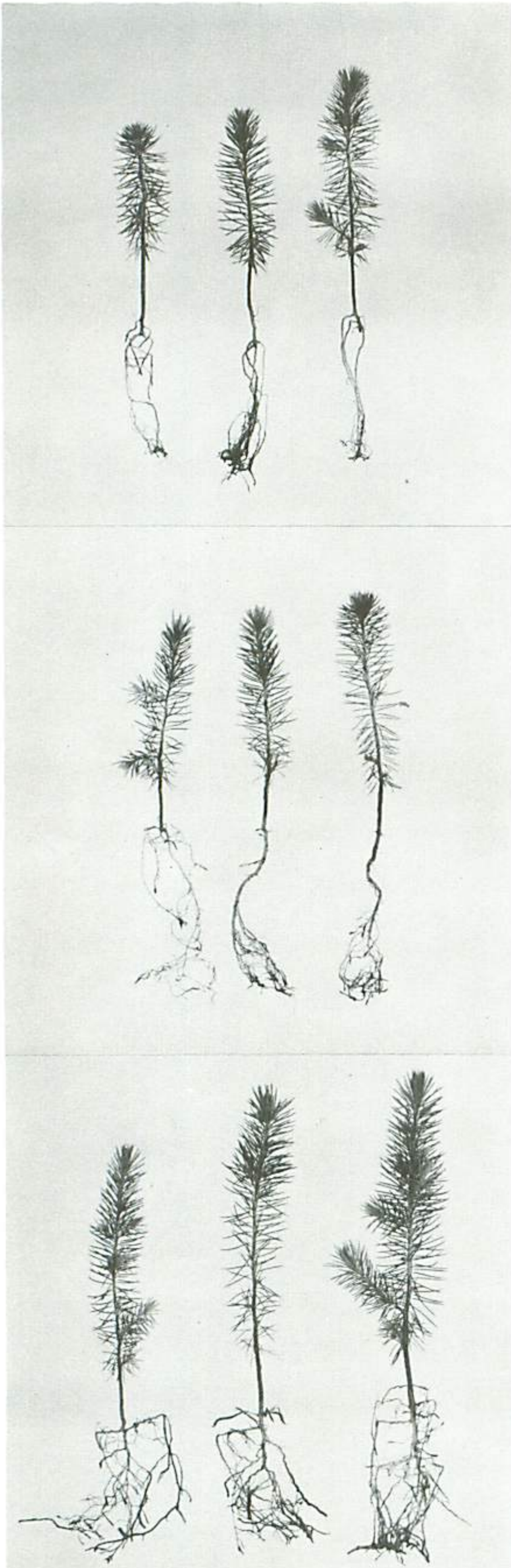

Frontispiece. Examples of 16-week-old white spruce seedlings grown in three sizes of plastic tube at three tube spacings. From top to bottom photographs show seedlings grown in 9/16-, 3/4- and 1 1/4-inch-diameter tubes, respectively. From left to right tubes were closely packed, 1 inch and 4 inches between tubes, respectively.

ABSTRACT

White spruce seedlings were grown for 16 weeks in three sizes of plastic tube (9/16-, 3/4- and 1 1/4-inch diameter) at three spacings (closely packed, 1 inch and 4 inches, respectively, between tubes). Growth was severely restricted in 9/16- and 3/4-inch-diameter tubes and at all spacings substantial improvements in seedling size were gained by using 1 1/4-inch tubes. The poorer growth in the former is attributed primarily to restricted rooting volume. It is concluded that an increased aerial spacing of seedlings does not compensate for a low soil volume, and that the superior results achieved by changing tube diameter from 9/16 inch to 1 1/4 inches cannot be duplicated by adopting a wider spacing of the smaller container. Despite some loss of growth potential owing to aerial competition, the most efficient alternative for improving seedling growth (relative to that in 9/16-inch tubes) was the use of 1 1/4-inch-diameter tubes at normal spacing.

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INTRODUCTION

The growing acreages of cutover land requiring regenerative treatments and the escalating costs of producing and planting conventional bare-root nursery stock have led, over the past decade, to increasing interest in the concept of container planting. Although container planting holds a number of potential advantages (Ackerman *et al.* 1965), the results achieved by its use in Canada, especially on an operational scale, have been extremely varied. Nevertheless, successes have been sufficiently numerous to ensure continued optimism, and it seems reasonable to predict increasing use of containerized seedlings in the future on sites to which they are suited.

Although a great variety of containers and container systems have been suggested for forestry use in recent years, relatively few have shown any real operational feasibility. One attribute common to all has been the small volume of contained soil available for rooting during the nursery production period. However, the small size of container has been dictated by economic considerations rather than biological desirability, and there is a growing awareness that some of the smallest containers in use may severely restrict seedling growth during the nursery phase as well as affect performance after planting.

Relationships between the volume of soil available for rooting and plant growth have been demonstrated for a number of agricultural crops (Baker and Woodruff 1962; Cornforth 1968; Stevenson 1967, 1970), although the nature of the relationship does not seem to be consistent for all species. For example, Stevenson (1967) found that, although the top weight of clover [*Trilobium* spp.], wheat [*Triticum aestivum* L.] and sunflower [*Helianthus annuus*] increased steadily with increasing soil volume, only sunflower showed any significant increase in root weight associated with increased soil volume. He later reported (Stevenson 1970) that soil volume was more effective than fertilizers in increasing the dry matter production of sunflowers and that fertilizers did not compensate for a low rooting volume.

Results with tree seedlings are generally in keeping with those obtained in the agricultural sphere, although, because of the greater similarity of growth habit, there is less reason to expect major differences in response between species.

Boudoux (1972) reported a general improvement in the growth of black spruce [*Picea mariana* (Mill.) B.S.P.] seedlings up to 18 weeks associated with increasing soil volume, but concluded that container diameter was considerably more effective in determining seedling growth than container length. Root development in particular was strongly influenced by container diameter (Boudoux 1970, 1972).

Other studies have also demonstrated significant improvements in seedling growth in response to increasing container diameter for lodgepole pine [*Pinus contorta* Dougl.] (Endean 1971), white spruce

[*Picea glauca* (Moench) Voss] and jack pine [*Pinus banksiana* Lamb. (= *P. divaricata* (Ait.) Dumont)] (Scarratt 1972, and in press). In both instances, seedlings grown in 9/16-inch- (currently used in Ontario) and 3/4-inch-diameter tubes 3 inches long showed severe restriction of root and shoot growth at 12-15 weeks from sowing. In white spruce and jack pine, adverse effects were evident only 8 weeks after sowing.

Although the results with tree seedlings have been interpreted mainly in relation to container diameter, it will be seen that, for closely packed containers, the aerial spacing of seedlings also increased with increasing container diameter. Questions arise, therefore, concerning the extent to which observed differences in growth could be attributed to container diameter, and the major additional influence, if any, that the associated changes in aerial spacing had upon development. Previous work with a limited range of tube diameters (Scarratt, in press) had suggested that the effects of aerial spacing were relatively minor, although there was no direct evidence for this. The study reported here was undertaken to test this hypothesis and to determine whether the subject warranted more detailed investigation.

MATERIALS AND METHODS

In this study only white spruce was used, because it is the most difficult of the common reforestation species to grow to plantable dimensions. The same three sizes of split-plastic tube were used as in previous studies:

1. 3-inch x 9/16-inch diameter (76 x 12 mm)[1]
2. 3 1/4-inch x 3/4-inch diameter (82 x 19 mm)
3. 3-inch x 1 1/4-inch diameter (76 x 31 mm)

When filled to within 1/4 inch of the tube lip, these tubes contained 0.7, 1.3 and 3.4 cubic inches (11, 22, 55 cubic centimeters) of soil, respectively.

Within each tube size, three spacing treatments were adopted: (i) tubes closely packed as in normal practice. (ii) 1 inch between tubes and (iii) 4 inches between tubes. The correct spacing was achieved by setting the tubes in position in wooden trays and filling the intervening spaces with coarse gravel. Each tube diameter x spacing combination was replicated four times, and consisted of a carefully spaced block of 25 (5 x 5) tubed seedlings. Of these 25 seedlings, the center nine (3 x 3) were designated as the treatment sample.

Seedlings were grown using methods recommended in the Ontario Department of Lands and Forests' (now the Ontario Ministry of Natural

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[1] Standard in Ontario.

Resources) manual "Provisional Instructions for Growing and Planting Tubed Seedlings" (Anon. 1967). Tubes were filled with a locally collected, well-decomposed peaty muck (pH 5.1), supplemented with potassium sulphate (70 g/m^3) and finely ground superphosphate (1240 g/m^3) during soil preparation. The trays were painted internally with copper paint to inhibit root growth from the bottom of the tubes (Saul 1968).

To promote as uniform a rate of germination as possible and to restrict differences in individual seedling growth resulting from variations in germination rate, the locally collected seed (single-tree origin) was soaked in tap water at 3^oC (38^oF) for 48 hours before sowing. Seeds were sown in March, 1971. Three seeds were sown per tube to avoid blanks and the possibilities of nonuniform growth owing to differences in seedling spacing within a single spacing unit. Seedlings were thinned to one per tube after primary needle development.

Seedlings were germinated and grown under greenhouse conditions. Daytime temperatures in the greenhouse ranged from 21^oC (70^oF) to 29^oC (85^oF), depending on external weather conditions; night temperatures were maintained at 21^oC. Daylength was extended to 16 hours by the use of low-intensity incandescent lamps (50 ft-c). Fertilization with a nutrient solution (RX-15) was begun 21 days after sowing and continued at 2-week intervals. To ensure that all seedlings received the same amount of nutrients, the solution was applied individually to each tube by pipettor.

After 16 weeks of growth, the nine central seedlings in each tray were removed for measurement of shoot height, root-collar diameter, side-shoot number, fresh weight and dry weight (48 hours at 70^oC (158^oF)).

RESULTS

Seedling response to the two treatment variables is summarized diagrammatically in Figures 1-5 (see Appendix), together with growth data for individual seedling characters. The significance of differences between treatment means were tested by Tukey's w procedure (Steel and Torrie 1960). In Table 1 the improvement in seedling growth[1] obtained by increasing the spacing of 9/16-inch-diameter tubes is compared with that achieved by increasing tube diameter.

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[1] Unless stated otherwise, seedling growth in 9/16-inch-diameter tubes at normal spacing is used as the basis for comparison.

Table 1. Effect of tube diameter and spacing on the relative size of 16-week-old white spruce tubed seedlings compared with the mean for seedlings grown in 9/16-inch-diameter tubes at normal spacing (n = 36)

	Percent improvement in--				
	Shoot ht	Root-collar diam	Side-shoot no.	Total fresh wt	Total dry wt
1. Effect of increasing diameter of closely packed tubes to--					
3/4 in.	2.1	0	18.0	12.3	8.8
1 1/4 in.	49.8	13.1	163.0	110.6	92.4
2. Effect of increasing spacing of 9/16-in.-diam tubes to--					
1 in.	0	1.9	52.3	13.0	4.6
4 in.	21.1	17.5	140.5	76.7	66.2

In general, seedlings responded more to an increase in tube diameter than to increased spacing. This was true for all characters measured (except root/shoot ratio, which showed no significant response to either factor), although treatment effects were relatively greater for seedling weight than for height or root-collar diameter. Although the effects of increased tube diameter were evident at all spacings, the effects of tube spacing *per se* were most clearly seen in the largest tube size. However, with one exception (shoot dry weight) there were no significant interactions between the effects of size and spacing.

No significant benefit was gained by increasing tube diameter from 9/16 to 3/4 inch at any tube spacing; for most characters measured the improvement in growth was small (2-10%). On the other hand, increasing tube diameter from 9/16 to 1 1/4 inches resulted in substantial and significant improvements in both seedling size and overall quality at all spacings, quality being expressed by such characteristics as sturdiness and branch/foliage density. On a percentage basis, for each character measured, these gains were of a similar magnitude for all tube spacings, averaging 19% for root-collar diameter, 50% for shoot height and 103% for total dry weight. Since root-shoot ratios were similar for all treatment combinations (averaging 0.46 for fresh weight, 0.33 for dry weight), improvements in root and shoot weights paralleled increases in total weight.

For most characters measured, seedlings grown in 1 1/4-inch-diameter tubes were also significantly superior to those grown in 3/4-inch tubes.

No significant improvement in seedling growth was obtained by increasing tube spacing from normal (i.e., closely packed) to 1 inch between tubes for any tube size. Any differences that did occur were most pronounced in the 1 1/4-inch-diameter tubes, where total dry weight was increased by 22%. However, shoot height was increased by only 4.5%. Growth increases in other tube sizes, when present, were generally much smaller, particularly in the 9/16-inch-diameter tube. The actual increase in side-shoot number in the latter (Fig. 3) was not as impressive as the figure for percentage increase might suggest (Table 1).

Fairly substantial increases in growth were achieved, at all tube diameters, by increasing spacing from normal to 4 inches between tubes. For example, shoot height was increased by an average of 20% and total dry weight by 63%. However, these increases were significant only for seedlings grown in the 1 1/4-inch-diameter tubes, and then only for root-collar diameter (26%) and weight (total fresh weight 70%; total dry weight 68%).

DISCUSSION

In terms of conventional closely packed containers, the results of this study reconfirm previously reported findings (Scarratt 1971, and in press) that:

> 9/16- and 3/4-inch-diameter plastic tubes severely restrict the growth of white spruce seedlings during a normal production period;
>
> for a given cultural regime, substantial improvements in seedling growth can be achieved within the same production period by increasing tube diameter to 1 1/4 inches.

The question at issue was whether container diameter was the primary factor determining seedling size, or whether associated changes in aerial spacing had any major influence upon growth. By implication, the possibility that seedling growth could be improved by increasing tube spacing rather than tube diameter was also under investigation.

Comparison of the relative effects of tube diameter and spacing suggests that previously observed differences in seedling response to tube size at normal spacing were, in fact, mainly attributable to differences in rooting volume. This conclusion is based on the evidence of height and weight data, both of which showed significantly greater increases for seedlings grown in 1 1/4-inch-diameter tubes at normal spacing than for 9/16-inch tubes at 1-inch spacing. Seedling-to-seedling distances were closely comparable in both instances, yet increased spacing alone resulted in an increase (relative to 9/16-inch tubes at normal spacing) of only 4.6% in dry weight, compared with 92.4% in response to increased tube diameter. The fact that increases in root-collar diameter and side-shoot number were not significantly different is not inconsistent with this conclusion; they would both be strongly influenced by aerial spacing, and might be expected to be similar.

Despite the foregoing conclusion, the evidence points to some degree of growth restriction by aerial competition at all tube diameters. Seedlings grown in 9/16- and 3/4-inch-diameter tubes showed no significant response to increased spacing, although there were fairly large increases in size associated with the change to 4-inch spacing. This suggests that, even for the smallest tube, low rooting volume was not the only constraint upon seedling growth at normal spacing, although it was the most important.

Although increasing tube diameter to 1 1/4 inches resulted in a substantial and significant improvement in seedling growth (Table 1), it is evident that fairly severe aerial competition was present at normal spacing in this tube size also. Although no significant improvement in seedling size resulted from increasing tube spacing to 1 inch, at 4-inch spacing shoot height was increased by 16% (not significant) and total dry weight by 68% (significant). The more pronounced response to tube spacing in the larger tube is interpreted as evidence that (1) the primary constraint upon seedling growth in 9/16- and 3/4-inch-diameter tubes at normal spacing came from low rooting volume, and (2) seedlings grown in 1 1/4-inch-diameter tubes at normal spacing were prevented from reaching the maximum growth potential of the soil volume by mutual competition in the aerial environment.

The results of this study show that the improvement in seedling growth achieved by increasing tube diameter from 9/16 to 1 1/4 inches could not be duplicated by increasing the spacing between 9/16- or 3/4-inch-diameter tubes instead. Four-inch spacing produced the closest approach to the results obtained with 1 1/4-inch tubes at normal spacing, but in terms of shoot height and dry weight, the differences in gain were still relatively large (Table 1).

The greater effectiveness of increasing container diameter rather than spacing is emphasized when one considers the space required to accommodate the same number of tubes (Table 2). Even if the same biological advantage had been gained with 9/16-inch-diameter tubes at 4-inch spacing as with 1 1/4-inch tubes at normal spacing, it would still be more efficient to use the latter, since the alternative (9/16-inch tubes at 4-inch spacing) would require 13 times more area to produce the same number of seedlings.

Table 2. Relative size of area required to accommodate the same number of tubes, for three tube sizes at three spacings

Tube spacing	Tube diameter 9/16 in.	3/4 in.	1 1/4 in.
Normal[a]	1.0	1.8	4.9
1 in.	7.1	9.7	16.0
4 in.	64.0	71.3	87.1

[a] Normal spacing = closely packed

Although other factors besides nursery space requirement will determine the overall economic efficiency of a given container system, space requirement is a major consideration within the limited context of production efficiency. The limitations of such simple comparisons, the relationship between treatment effects and space requirement provides a useful means of ranking diameter and spacing alternatives by their "relative efficiency". In the treatment comparisons that follow, efficiency ratings have been derived by weighting relative seedling size after 16 weeks (Table 1 + 100) by the reciprocal of the relative area requirement (Table 2) for a given container size. Ratings have been adjusted to a scale of 1 to 100.

	Relative efficiency in terms of -- Shoot ht	Total dry wt
1 1/4-in. diam at normal spacing	100	100
9/16-in. diam at 1-in. spacing	46	38
9/16-in. diam at 4-in. spacing	6	7

It is clear that increasing tube diameter from 9/16 inch to 1 1/4 inches was not only biologically more effective but, in terms of area requirement, also more efficient as a means of improving seedling growth than the two spacing alternatives used with 9/16-inch-diameter tubes.

CONCLUSIONS

This study confirms previous work which showed that both 9/16- and 3/4-inch-diameter plastic tubes severely restrict the growth of white spruce seedlings from an early age. A significant improvement in seedling growth can be achieved by increasing tube diameter to 1 1/4 inches. Use of this larger container would facilitate growing a larger seedling within the same production period or, alternatively, shorten the growth period required to produce a given size of planting stock.

Comparison of the effects of tube spacing shows that the poorer growth of seedlings in 9/16- and 3/4-inch-diameter tubes at normal spacing is primarily a result of restricted rooting volume. Increasing the spacing between tubes does not compensate for a low soil volume, and the results achieved by increasing tube diameter from 9/16 to 1 1/4 inches cannot be duplicated by adopting a wider spacing of 9/16- and 3/4-inch-diameter tubes instead.

Despite the substantial improvement in seedling size obtainable by increasing tube diameter to 1 1/4 inches, growth in closely packed tubes may fall short of the full growth potential of the larger rooting volume as a result of aerial competition between seedlings. For white spruce raised in this size of tube, the effects of inadequate spacing are likely to restrict growth during the course of a normal production period. However, it would be impracticable to adopt the wide container spacing necessary to avoid such growth restriction, and in practical terms the most efficient means of improving seedling growth is by the use of 1 1/4-inch-diameter tubes at normal spacing.

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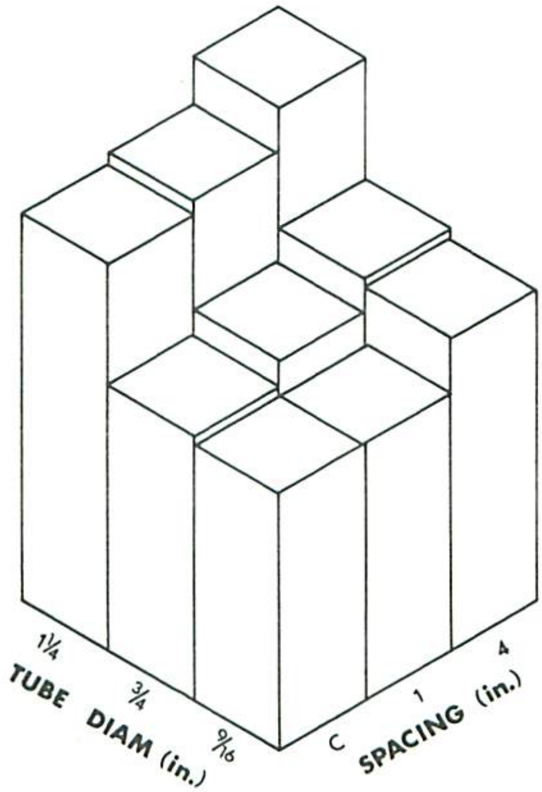
APPENDIX

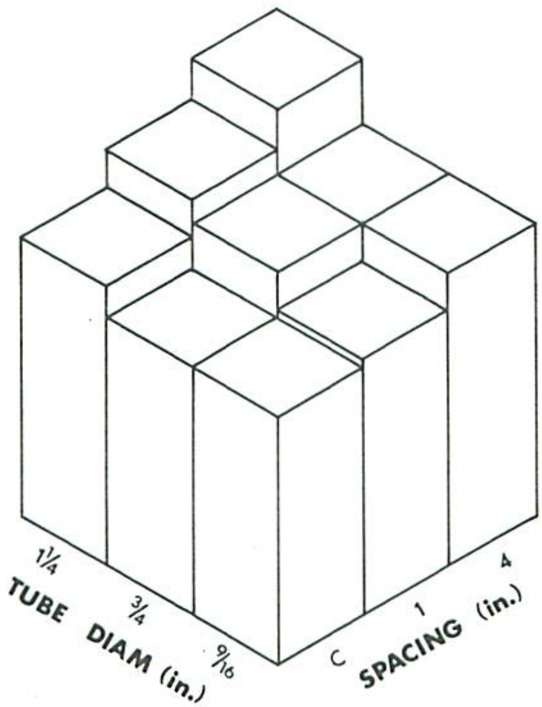


Mean shoot height (mm)*

		Tube diameter		
		9/16"	3/4"	1 1/4"
Tube spacing	Control	65.4a	66.8a	98.0bc
	1"	65.4a	74.7a	102.4c
	4"	79.2a	82.1ab	113.5c

* Means not followed by a common letter are significantly different at the 5% level.

Fig. 1 Effect of tube diameter and spacing on the height growth of 16-wk-old white spruce tubed seedlings (n = 36).

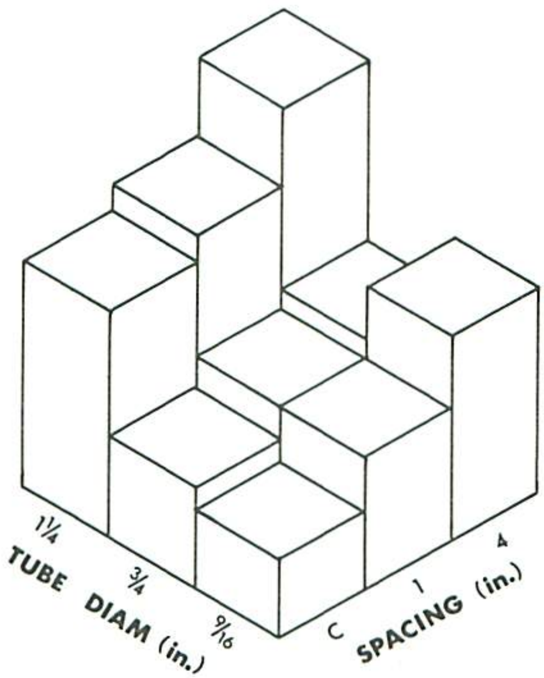


Mean root-collar diameter (mm)*

		Tube diameter		
		9/16"	3/4"	1 1/4"
Tube spacing	Control	1.60a	1.58a	1.81ab
	1"	1.63a	1.86ab	2.02bc
	4"	1.88ab	1.86ab	2.28c

* Means not followed by a common letter are significantly different at the 5% level.

Fig. 2 Effect of tube diameter and spacing on the root-collar diameter of 16-wk-old white spruce tubed seedlings (n = 36).

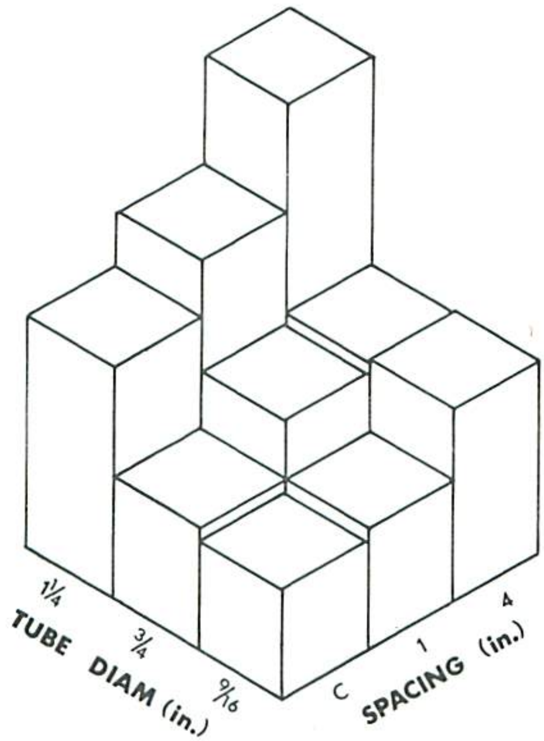


Mean side-shoot number*

		Tube diameter		
		9/16"	3/4"	1 1/4"
Tube spacing	Control	1.1a	1.3ab	2.9cde
	1"	1.7abc	1.7abc	3.2de
	4"	2.7bcd	1.9abcd	4.2e

* Means not followed by a common letter are significantly different at the 5% level.

Fig. 3 Effect of tube diameter and spacing on side-shoot development in 16-wk-old white spruce tubed seedlings (n = 36).

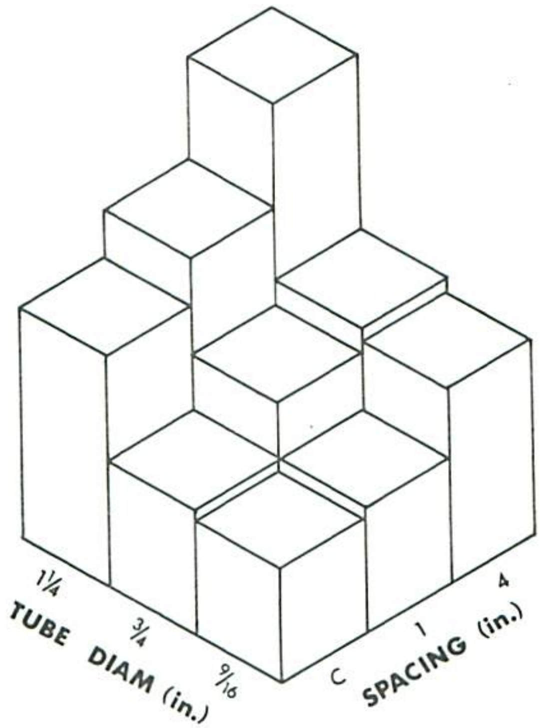


Mean total fresh weight (mg)*

		Tube diameter		
		9/16"	3/4"	1 1/4"
Tube spacing	Control	560a	629a	1180bc
	1"	633a	923abc	1449cd
	4"	990abc	961abc	2005d

* Means not followed by a common letter are significantly different at the 5% level.

Fig. 4 Effect of tube diameter and spacing on the total fresh weight of 16-wk-old white spruce tubed seedlings (n = 36).



Mean total dry weight (mg)*

		Tube diameter		
		9/16"	3/4"	1 1/4"
Tube spacing	Control	153a	167a	294bc
	1"	160a	235ab	359c
	4"	254abc	258abc	493d

* Means not followed by a common letter are significantly different at the 5% level.

Fig. 5 Effect of tube diameter and spacing on the total dry weight of 16-wk-old white spruce tubed seedlings (n = 36).