EFFECTS OF CONTAINER VOLUME AND SHAPE ON THE GROWTH OF BLACK SPRUCE

(*Picea mariana* (Mill.) B.S.P.) SEEDLINGS

by

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree

of Masters of Science in Forestry

School of Forestry

Lakehead University

May 24, 1984

ABSTRACT

Sutherland, D.C. 1984. Effects of container volume and shape in the growth of black spruce (*Picea mariana* (Mill) B.S.P.) seedlings. Major Advisor: Professor R.J. Day.

Key Words: black spruce, container shape, container volume, field outplanting, greenhouse production, morphological characteristics, *Picea mariana* (Mill.) B.S.P., seedling growth, stock quality.

The objective of this thesis was to evaluate the growth of black spruce seedlings in containers with four soil volumes (45, 90, 180, 360 cm^3) and at three diameter/depth shapes (1:2, 1:3, 1:4). Seedling height, root collar diameter, top dry weight and root dry weight were measured after 16 weeks in the greenhouse and after one growing season in the field. Analyses of variance (ANOVA) and multiple linear regressions (MLR) were completed for each of the morphological characteristics and for the corresponding seedling quality indices. The ANOVAs and MLRs were used to evaluate seedling growth and quality in order to determine the optimum container volume and shape necessary for the production of high quality black spruce stock. The growth and quality of black spruce stock significantly increased with increasing container volume and with change in container shape from deep and narrow (1:4 diameter/depth ratio) to shallow and wide (1:2 diameter/depth ratio). These changes were detected in the greenhouse production phase and became very evident after outplanting in the field.

To produce high quality black spruce seedlings for outplanting, the container volume should exceed 80 cm^3 and the container shape should have a 1:2 diameter/depth ratio. Black spruce grown in 1:2 diameter/depth shaped containers that range from 80 to 180 cm^3 in volume will be of high quality and have a total dry weight between 1.0 and 1.4 g after 16 weeks in a greenhouse. Black spruce grown in 1:2 diameter/depth shaped containers that range from 180 to 360 cm^3 in volume will be of superior quality and have a total dry weight between 1.4 and 1.7 g after 16 weeks in a greenhouse.

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ACKNOWLEDGEMENTS

I wish to express my sincere thanks to my major advisor, Professor R. J. Day for his guidance and inspiring support and for the use of his computer system. I am also grateful to Dr. G. Hazenberg and Dr. R. W. Tinus for their guidance, constructive criticism and review of the manuscript.

I am thankful to Ian H. Burgess for his technical assistance in the greenhouse, and to my fellow graduate students for their support throughout the course of its completion.

I am grateful to the Canadian Forestry Service and Lakehead University for providing financial support.

Finally, I wish to express my sincere appreciation to my wife Anne for typing this manuscript and for her understanding, patience, moral support and sacrifices she has made these past years.

INTRODUCTION

A great variety of containers have been manufactured over the past twenty years for tree seedling production (Table 1). At present Canadian nurseries are mainly using four types of containers, Spencer-Lemaire Bookplanters, Multipots, Japanese Paperpots, and Styroblocks. Each type of container can supply a range of volumes and shapes for specific greenhouse production and outplanting requirements. These containers range from 33 to 700 cm^3 in volume and from 1:2 to 1:7 in diameter/depth dimension or shape (Table 1).

Although there is such a wide variety of container volumes and shapes that may be selected for stock production, northern Ontario nurseries have opted to use small containers with volumes that range from 40 to 70cm^3 and shapes that range from 1:2 to 1:3 in diameter/depth. Although these containers are economical to use, because more seedlings can be produced in a greenhouse, they do not provide sufficient growing space for proper seedling development in the greenhouse or produce adequately large seedlings for field establishment. The selection of a small volume container may keep nursery and planting costs low but more consideration should be given to a higher quality seedlings and optimum field establishment (Tinus, 1981). By considering the biological requirements of a seedling, and not just the production costs, seedlings of superior quality can be produced which will minimize the final costs of establishing trees free to grow in the field.

In order to optimize container dimensions, nurserymen and silviculturists must understand how the volume and shape of a container affects tree seedling growth and

TABLE 1. Types of containers used for tree seedling production and their abbreviated names, size and shape

Type of Container	Name Abbreviation	Container Volume (cm^3)	Container Size Diameter x Depth (cm) (cm)	Container Shape Diam/Depth Ratio
Ashphalt tube	AT	205	5.0 x 10.0	1:2
Conwed				
-small	C-S	30	1.6 x 15.0	1:9
-medium	C-M	74	2.5 x 15.0	1:6
-large	C-L	294	5.0 x 15.0	1:3
Fertil-pot				
-small	FP-S	180	9.0 x 7.0	1:1
-large	FP-L	755	10.0 x 18.0	1:2
Grow Block	GB	20	1.9 x 9.0	1:5
Jiffy Pellet	JP-7	70	4.5 x 7.0	1:2
Jiffy Pot				
-522	JP-522	33	3.5 x 5.1	1:2
-515	JP-515	61	4.7 x 5.1	1:1
Japanese Paper Pot				
-213	JPP-213	33	2.0 x 13.0	1:7
-313	JPP-313	75	3.0 x 13.0	1:4
-315	JPP-315	88	3.0 x 15.2	1:5
-408	JPP-408	70	3.8 x 7.6	1:2
-415	JPP-415	140	3.8 x 15.2	1:4
-508	JPP-508	121	5.1 x 7.6	1:2
-608	JPP-608	175	6.1 x 7.6	1:1
Multipot				
-1	MP-1	58	3.3 x 9.0	1:3
-2	MP-2	67	3.3 x 12.0	1:4
-4	MP-4	136	4.0 x 16.4	1:4
Ontario Tube				
-small	OT-S	12	1.4 x 7.7	1:6
-medium	OT-M	22	1.9 x 7.7	1:4
-large	OT-L	62	3.2 x 7.7	1:2
Peat Pot	PP	157	6.0 x 8.0	1:1
Peat Stick	PS	45	3.0 x 15.0	1:5
Spencer-Lemaire				
-Ferdinand	SL-F	40	2.1 x 10.1	1:4
-Five	SL-5	55	2.5 x 10.4	1:4
-Hillson	SL-H	150	3.8 x 12.7	1:3
-Tinus	SL-T	500	4.3 x 20.5	1:4
-Super 45	SL-45	700	5.7 x 25.0	1:4
Styroblock				
-2	STY-2	35	2.4 x 11.0	1:5
-2A	STY-2A	35	2.4 x 11.0	1:5
-4	STY-4	60	3.0 x 12.5	1:4
-4A	STY-4A	58	2.8 x 13.5	1:5
-8	STY-8	115	3.8 x 15.0	1:4
-20	STY-20	330	5.9 x 15.0	1:3
Todd Planter				
-100A	TP-100A	25	2.5 x 7.5	1:3
-150	TP-150	75	3.8 x 12.5	1:3
-200	TP-200	75	5.0 x 7.5	1:2
Tree Planter	TrP-ITW	107	2.5 x 15.0	1:6
Tree Starter	TS	65	3.2 x 12.5	1:4
Walter's Bullet				
-small	WB-S	20	2.0 x 6.4	1:3
-large	WB-L	36	2.0 x 11.4	1:6

survival both in the greenhouse production phase and after field outplanting.

The purpose of this thesis was to evaluate the growth of black spruce (*Picea mariana* (Mill.) B.S.P.) seedlings in containers with four volumes (45, 90, 180 and 360 cm^3) and at three diameter/depth shapes (1:2, 1:3, 1:4). Seedling height, root collar diameter, top dry weight and root dry weight were measured after 16 weeks in the greenhouse and after one growing season in the field. Analyses of variance (ANOVA) and multiple linear regressions (MLR) were completed for each of the morphological characteristics and for the corresponding seedling quality indices. The ANOVAS and MLRS were used to evaluate seedling growth and quality in order to determine the optimum container volume and shape necessary for the production of high quality black spruce stock.

In Ontario over 18 million black spruce container seedlings were shipped for planting in 1983 and the 1984 production targets are even greater (Tiemann, pers. comm., 11 May 84). The potential significance of improving the existing quality of black spruce container stock would be of great biological and economical importance.

LITERATURE REVIEW

In the past the growth and survival of container stock has been correlated with the single or combined effects of container diameter, depth, and volume. Most commonly these correlations have been made between growth and soil volume (Endean, 1972a; Van Eerden, 1974; Karlsson and Kovats, 1974). In several instances correlations were obtained between container diameter and depth without sufficient attention paid to the associated change in soil volume (Scarratt, 1972b, 1972c; Davis and Whitcomb, 1975; Berger and Lysholm, 1978; Solberg, 1978). In the well designed research on this subject growth was correlated with change in diameter and depth in containers of constant volume (Endean and Carlson, 1975; Carlson and Endean, 1976; Biran and Elliassaf, 1980a).

This review will primarily address studies that have correlated the growth and survival of container nursery stock to container size and shape in the greenhouse production phase and after field outplanting.

For simplicity in review, the comprehensive literature on the effects of container size and shape on seedling growth are summarized in Tables 2 to 10. Without this quantitative approach general trends found in the review tend to be misleading. The tables are divided by genera and species and information is given as follows:

1) Author and date of publication,

2) Type of container tested,

3) Container size and shape,

4) Seedling age and size at the end of the greenhouse production phase,

5) Seedling age, size and per cent survival after outplanting.

WHITE SPRUCE

White spruce (*Picea glauca* (Moench) Voss) has been more commonly studied than other species. A total of eleven reports have been published on the effect container volume and shape has had on the growth of white spruce (Table 2). However, the data collected is rather incomplete. Only a few publications incorporated the results of both greenhouse and field trials. Considerable data has been recorded in greenhouse experiments whereas only a minimal amount of data has been recorded in the field. The majority of researchers that did follow the progress of white spruce into the field only measured seedling height and per cent survival and did not measure dry weight. Height is a poor indicator of growth and although per cent survival does measure establishment well, it is not an indicator for growth.

Greenhouse Production Phase

The literature shows that there is considerable variation in all the morphological characteristics: height, root collar diameter and dry weight of white spruce between the various studies (Table 2). Seedling dry weights ranged from 0.05 g (Scarratt, 1972b) to 5.5 g (Scarratt, 1973) over a 12 and 18 week growth period. Heights also varied considerably from 1.2 cm (Scarratt, 1972b) to 22 cm (McMinn, 1981) over a 12 and 16 week growth period. The small range of 4 to 6 weeks between the greenhouse growth periods could not possibly account for this variation. The growth environments and cultural treatments used in each study are probably more influential and may be responsible for

TABLE 2. The morphological characteristics of containerized white spruce seedlings found in greenhouse and outplanting studies.

Species[1]	Author & Date	Container Type	Container Size & Shape: Volume (cm^3)	Diameter (cm)	Depth (cm)	Dimension (Diam/Depth)	Greenhouse Phase, Seedling Age & Size: Age (wks)	Ht. (cm)	RCD (mm)	SDW (g)	Outplanting Phase, Seedling Age & Size: Age (yrs)	Ht. (cm)	RCD (mm)	SDW (g)	Survival: Time (yrs)	%
PIg	Van Eerden	OT-S	12	1.4	7.7	1:6	-	-	-	-	-	-	-	-	3	39
	1971	OT-M	22	1.9	7.7	1:4	-	-	-	-	-	-	-	-	3	43
	1972	WB-S	20	2.0	6.4	1:3	-	-	-	-	-	-	-	-	3	46
		WB-L	36	2.0	11.4	1:6	-	-	-	-	-	-	-	-	3	58
PIg	Endean	OT	12	1.4	7.7	1:6	16	-	-	0.29	3	-	-	0.19	-	-
	1972b	C-M	74	2.5	15.0	1:6	16	-	-	0.24	3	-	-	0.12	-	-
PIg	Scarratt	OT-M	22	1.9	7.7	1:6	12	1.2	0.4	0.05	3	17.5	3.0	-	3	88
	1972b	OT-L	62	3.2	7.7	1:2	12	5.9	4.5	0.23	3	23.5	4.4	-	3	98
PIg	Scarratt	OT-S	12	1.4	7.7	1:6	16	7.0	1.7	0.19	-	-	-	-	-	-
	1972c	OT-M	22	1.9	7.7	1:4	16	7.5	1.8	0.22	-	-	-	-	-	-
		OT-L	62	3.2	7.7	1:2	16	10.5	2.0	0.38	-	-	-	-	-	-
PIg	Scarratt	OT-S	12	1.4	7.7	1:6	18	7.0	-	1.50	-	-	-	-	-	-
	1973	OT-M	22	1.9	7.7	1:6	18	7.5	-	2.00	-	-	-	-	-	-
		OT-L	62	3.2	7.7	1:2	18	12.0	-	4.50	-	-	-	-	-	-
		Manuf.	157	5.1	7.7	1:2	18	13.5	-	5.50	-	-	-	-	-	-
PIg	Carlson &	Manuf.	10	1.6	4.8	1:3	20	2.3	-	0.09	-	-	-	-	-	-
	Endean		33	2.4	7.2	1:3	20	4.0	-	0.18	-	-	-	-	-	-
	1976		66	3.0	9.0	1:3	20	5.9	-	0.32	-	-	-	-	-	-
			131	3.8	11.4	1:3	20	7.9	-	0.45	-	-	-	-	-	-
			262	4.8	14.4	1:3	20	8.6	-	0.52	-	-	-	-	-	-
			524	6.1	18.3	1:3	20	8.8	-	0.54	-	-	-	-	-	-
PIg	Carlson &	Manuf.	All Volumes		-	1:1	20	-	-	0.39	-	-	-	-	-	-
	Endean		All Volumes		-	1:3	20	-	-	0.31	-	-	-	-	-	-
	1976		All Volumes		-	1:6	20	-	-	0.26	-	-	-	-	-	-
PIg	McMinn	STY-2	35	2.4	11.0	1:5	-	-	-	-	5	-	-	0.15	-	-
	1978	STY-8	115	3.8	15.0	1:4	-	-	-	-	5	-	-	0.21	-	-
PIg	Van Eerden	STY-2A	35	2.4	11.0	1:5	16	13.0	2.3	1.20	-	-	-	-	-	-
	1981	STY-4A	58	2.8	13.5	1:5	16	17.0	2.7	1.50	-	-	-	-	-	-
		STY-8	115	3.8	15.0	1:4	16	20.0	4.3	4.50	-	-	-	-	-	-
PIg	Walker	STY-2	35	2.4	11.0	1:5	-	-	-	-	5	25.0	-	-	-	-
	1981	SL-F	40	2.1	10.0	1:4	-	-	-	-	5	40.0	-	-	-	-
		SL-H	150	3.8	13.0	1:3	-	-	-	-	5	46.0	-	-	-	-
PIg	Gardner	WB-S	20	2.0	6.4	1:3	12	10.0	1.9	0.80	5	35.0	-	-	5	95
	1981	STY-2	35	2.4	11.0	1:5	12	16.0	2.0	0.99	5	39.0	-	-	5	91
PIg	McMinn	STY-2	35	2.4	11.0	1:5	16	16.0	-	0.80	2	28.0	-	-	2	91
	1981	STY-4	60	3.0	12.5	1:4	16	20.0	-	1.50	2	35.0	-	-	2	96
		STY-8	115	3.8	15.0	1:4	16	22.0	-	2.10	2	40.0	-	-	2	99

[1] Note: Description of species abbreviations in Appendix I.

the variation. The container volume available for root development may be one environmental condition to consider.

Over the past ten years there has been a trend towards testing and using containers with larger volumes. Ten years ago, small volume containers were generally used (Table 2). This could be atributed to the popularity of the Ontario Tube of that time period. As time progressed researchers realized some of the limitations of small containers in the 10 to 30 cm^3 range and began testing larger containers in the 60 to 500 cm^3 range.

The growth of white spruce was severely restricted in small containers less than 30 cm^3 in volume (Table 2). Because of this, 30 cm^3 can be considered to be the lower limit of volume for effective container size. In 30 cm^3 containers seedling height, root collar diameter and dry weight were well below current minimum standards (Roller, 1977). All morphological characteristics increased as container volumes increased above this restrictive lower limit (Table 2). The only exception to this trend was found in a study by Endean (1972b) in which the seedling dry weight slightly decreased as the container volume was enlarged. Data presented in Table 2 show that seedling dry weight responded more to increases in container volume than height. Generally there was a 300 per cent increase in seedling dry weight when container volume tripled (Scarratt, 1972b, 1972c, 1973; Carlson and Endean, 1976; Van Eerden, 1981). Height and root collar diameter also increased by roughly 150 per cent when container volume tripled. Carlson and Endean (1976) concluded that the time to produce a specific volume white spruce seedling can be reduced from 20 to 15 weeks when the container volume was increased from 40 to 120 cm^3.

Although there is a distinct trend for improved growth of white spruce seedling by increasing container volume, there are upper limits . In several studies seedling growth showed no significant improvement with further increases in container volume over 120 cm^3 (Scarratt, 1973; Carlson and Endean, 1976).

There was only one study that assessed the relationship between seedling growth and container shape without including the influences from changes in container volume. Carlson and Endean (1976) found that seedling dry weight decreased when the shape of the container changed from a shallow, wide container (1:1 diameter/depth) to a deep, narrow container (1:6 diameter/depth) (Table 2).

Outplanting Phase

White spruce field results are more difficult to assess owing to the lack of data (Table 2). Only Endean (1972b) and McMinn (1978) recorded seedling dry weight. These two studies showed that their seedling dry weights were similar 3 to 5 years after outplanting. The height and per cent survival data also showed little variation.

All seedling heights and per cent survivals were still significantly different after five growing seasons. The height of seedlings grown in large volume containers remained twice as tall as those grown in smaller containers (McMinn, 1981; Walker, 1981).

None of the studies assessed the relationship between white spruce growth in the field and container shape without removing the influences from changes in container volume.

BLACK SPRUCE

Although black spruce (*Picea mariana* (Mill.) B. S. P.) is one of the most important commercial species in Canada very few researchers have studied the effect container volume and shape has on its growth (Table 3). Of the two greenhouse studies only the work of Scarratt (1981) can be used to evaluate growth trends. In addition two field studies can also be constructively used.

Greenhouse Production Phase

Data variation and growth trends for black spruce are difficult to determine since there are only two documented reports (Roller, 1976; Scarratt, 1981). The seedling heights over time are quite different between studies. During a 16 week growth period Roller (1976) produced 5 to 8 cm trees whereas Scarratt (1981) produced trees that were more than twice as tall, 15 to 18 cm, under the same growing period and container volume range (Table 3). Evidently environmental conditions and cultural treatments other than container volume and shape must have influenced the seedling growth.

Scarratt (1981) found that seedling height, root collar diameter and dry weight all increased with an increase in container volume from 70 to 121 cm3 cm. His work may suggest that 121 cm^3 be an upper volume limit since the next largest container volume (175 cm^3) produced substantially smaller seedlings. Scarratt does not explain the reason for this anomaly. An upper volume limit of 121 cm^3 parallels the upper limits of 120 cm^3 for white spruce (Table 2).

None of the studies assessed the relationship between the growth of black spruce in the greenhouse and container shape without removing the influences from changes in container volume.

Outplanting Phase

Variation in the data given in Table 3 is hard to evaluate because there are only three studies. Each of these report on seedlings of a different age (Roller, 1976, 1977; Scarratt, 1981).

The two studies reported by Roller (1976) and (1977) show poor growth trends with increasing container volume. All morphological characteristics generally increased slightly with increases in container volume (Table 3). The inconsistent growth of seedlings in the Jiffy Pot and Peat Pot containers are not explained but may be owing to surface evaporation, water retention problems or wicking. These porous walled containers may have dried out more rapidly than the others. Survival rates do not correlate with changes in container volume except for a weak positive trend to increase with increased volume (Scarratt, 1981).

None of the studies assessed the relationship between the growth of black spruce after outplanting and container shape without removing the influences from changes in container volume.

OTHER SPRUCES

Norway spruce (*Picea abies* (L.) Karst.) was the only other spruce studied. It was examined by deChamps (1978) and Roller (1976) to assess the relationship between seedling growth and container volume (Table 4). In the greenhouse production phase Roller (1976) only measured height and deChamps (1978) did not make any measurements. However,

TABLE 3. The morphological characteristics of containerized black spruce seedlings found in greenhouse and outplanting studies.

Species[1]	Author & Date	Container Type	Container Size & Shape: Volume (cm³)	Diameter (cm)	Depth (cm)	Dimension (Diam/Depth)	Greenhouse Phase, Seedling Age & Size: Age (wks)	Ht. (cm)	RCD (mm)	SDW (g)	Outplanting Phase, Seedling Age & Size: Age (yrs)	Ht. (cm)	RCD (mm)	SDW (g)	Survival: Time (yrs)	%
PIm	Roller 1976	STY-2	35	2.4	11.0	1:5	16	7.0	-	-	3	30.0	4.8	8.90	3	73
		MP-1	58	3.3	9.0	1:3	16	8.0	-	-	3	38.0	6.0	14.90	3	66
		JP-7	72	4.5	7.0	1:2	16	7.0	-	-	3	36.0	4.9	9.10	3	65
		STY-8	115	3.8	15.0	1:4	16	8.0	-	-	3	35.0	5.8	13.30	3	79
		PP-S	157	6.0	8.0	1:1	16	5.0	-	-	3	33.0	4.9	9.70	3	70
PIm	Roller 1977	STY-2	35	2.4	11.0	1:5	-	-	-	-	1	13.0	2.7	0.90	2	65
		SL-F	40	2.1	10.0	1:4	-	-	-	-	1	-	-	-	2	52
		MP-1	58	3.3	9.0	1:3	-	-	-	-	1	13.0	2.4	0.80	2	92
		STY-4	60	3.0	12.5	1:4	-	-	-	-	1	14.0	2.8	1.10	2	65
		JPP-408	70	3.8	7.6	1:2	-	-	-	-	1	19.0	2.3	0.90	2	80
		STY-8	115	3.8	15.0	1:4	-	-	-	-	1	16.0	3.5	1.60	2	69
PIm	Scarratt 1981	JPP-408	70	3.8	7.6	1:2	16	15.0	2.9	1.42	-	-	-	-	3	91
		JPP-508	121	5.1	7.6	1:2	16	18.0	3.7	2.29	-	-	-	-	3	94
		JPP-608	175	6.1	7.6	1:1	16	16.0	3.6	1.63	-	-	-	-	3	95

TABLE 4. The morphological characteristics of containerized norway spruce seedlings found in greenhouse and outplanting studies.

Species[1]	Author & Date	Container Type	Container Size & Shape: Volume (cm³)	Diameter (cm)	Depth (cm)	Dimension (Diam/Depth)	Greenhouse Phase, Seedling Age & Size: Age (wks)	Ht. (cm)	RCD (mm)	SDW (g)	Outplanting Phase, Seedling Age & Size: Age (yrs)	Ht. (cm)	RCD (mm)	SDW (g)	Survival: Time (yrs)	%
PIa	Roller 1976	STY-2	35	2.4	11.0	1:5	16	5.6	-	-	3	28.0	5.3	7.10	3	73
		MP-1	58	3.3	9.0	1:3	16	4.8	-	-	3	28.0	5.0	9.40	3	66
		JP-7	70	4.5	7.0	1:2	16	7.0	-	-	3	29.0	5.2	8.40	3	65
		STY-8	115	3.8	15.0	1:4	16	8.3	-	-	3	31.0	6.5	15.00	3	79
		PP	157	6.0	8.0	1:1	16	5.0	-	-	3	21.0	3.6	3.90	3	70
PIa	deChamps 1978	FP-S	180	9.0	7.0	1:1	-	-	-	-	10	242.0	7.6	-	2	98
		FP-L	755	10.0	18.0	1:2	-	-	-	-	10	283.0	9.4	-	2	96

[1] Note: Description of species abbreviations in Appendix I.

both workers measured adequate information in the field trials.

Greenhouse Production Phase

Because of the lack of data the relationship between seedling height and container volume could only be assessed in Rollers (1976) work. Height generally increased with an increase in container volume up to 115 cm^3 (Table 4). The next largest container volume, the Peat Pot container produced shorter trees.This may again be owing to surface evaporation, water retention problems or wicking as mentioned for black spruce.

None of the studies assessed the relationship between the growth of Norway spruce in the greenhouse and container shape without removing the influences from changes in container volume.

Outplanting Phase

After three growing seasons seedling height, root collar diameter and dry weight all improved with increases in container volume (Table 4). The dry weight doubled from 7 to 15 g with a container volume increase from 35 to 115 cm^3 (Roller 1976). There were, however, no differences in per cent survival with changes in container volume.

None of the studies assessed the relationship between the growth of Norway spruce after outplanting and container shape without removing the influences from changes in container volume.

JACK PINE

Jack pine (*Pinus banksiana* Lamb.) has often been studied (Table 5). Six papers have attempted to evaluate the relationship between the growth of jack pine seedlings and container volume. Equal emphasis has been placed on greenhouse and outplanting studies. Morphological attributes were adequately measured in all four greenhouse studies. The five field studies mainly recorded height and per cent survival. The best report was by Alm et al (1982) they also measured seedling dry weight. The data collected for jack pine was by far superior in quantity and quality over all other coniferous data.

Greenhouse Production Phase

The variation of jack pine growth data was considerable from worker to worker (Table 5).Seedling height varied from as low as 2 cm (Scarratt, 1972b) to as high as 22 cm (Scarratt, 1981) over a 12 and 16 week growth period. The most variation was for seedling dry weight which ranged from 0.04 g (Scarratt, 1972b) to 4.22 g (Scarratt, 1981) over the above mentioned growth periods. Some of this variation can be attributed to the four week difference between the growth periods, but most is probably related to environmental and cultural treatment differences. The principal influence may be from changes in container volume.

Container volumes ranging from 12 to 175 cm^3 have been tested over the past ten years. Walker (1981) tested a container volume above this range but provided only limited data.

Jack pine growth was found to be restricted in small volume containers less than 30 cm^3 (Table 5). This may again be considered the lower volume limit as it was for white and black spruce. All morphological characteristics measured from seedlings grown in such small containers were below current minimum standards. Growth improved when container volumes were enlarged beyond this minimum volume limit. When container volume doubled from roughly 60 to 120 cm^3 all morphological characteristics of the seedlings increased. The most substantial improvement was the 200 per cent increase in seedling dry weight (Scarratt, 1972b, 1973, 1981; Alm et al, 1982). Height and root collar diameter also significantly improved when container volume was increased except in a few cases when the container volume exceeded 90 to 120 cm^3 (Scarratt, 1981; Alm et al, 1982.). No explanations were given for these anomalies.

None of the studies assessed the relationship between jack pine seedling growth in the greenhouse and container shape without removing the influences from changes in container volume.

Outplanting Phase

Jack pine seedling height and root collar diameter varied considerably after three growing seasons (Table 5). Heights varied from 41 cm (Alm et al, 1982) to 124 cm (Carlson and Nairn, 1977). The root collar diameters ranged from 9 mm (Alm et al, 1982) to 22 mm (Carlson and Nairn, 1977).

Jack pine grown in progressively larger containers maintained their superiority in volume after three growing seasons (Table 5). Seedling height and root collar diameter continued to improve as container volume increased in all studies except in one by Carlson and Nairn (1977). Their height results showed no trend for increased growth with increasing container volume and they do not explain this anomaly. Per cent survival could not be constructively used owing to high survival rates attained at all container volumes (Scarratt, 1972b, 1981).

None of the studies assessed the relationship between jack pine seedling growth after outplanting and container shape without removing the influences from changes in container volume.

OTHER PINES

Researchers have also studied the effects container volume and shape have on the growth of lodgepole pine (*Pinus contorta* Doug. var *latifolia* Engelm.), slash pine (*Pinus elliottii* Engelm.), ponderosa pine (*Pinus ponderosa* Laws.), loblolly pine (*Pinus taeda* L.), red pine (*Pinus resinosa* Ait.), and caribbean pine (*Pinus caribaea* Morelet) (Table 6). Although the data collected for these species was very limited and incomplete there are some trends that should be noted.

Greenhouse Production Phase

Table 6 shows that there are lower limits of container volume for these pines especially for lodgepole pine. Container volumes below 30 cm^3 restricted growth and produced substantially poor quality seedlings (Endean, 1972b, 1973; Endean and Carlson, 1975).

As container volumes increased above this lower volume limit there was a general trend for seedlings to produce more dry weight (Endean, 1973; Van Eerden, 1974, 1978; Endean and Carlson, 1975; Gardner, 1981).

TABLE 5. The morphological characteristics of containerized jack pine seedlings found in greenhouse and outplanting studies.

Species[1]	Author & Date	Container Type	Container Size & Shape: Volume (cm³)	Diameter (cm)	Depth (cm)	Dimension (Diam/Depth)	Greenhouse Phase, Seedling Age & Size: Age (wks)	Ht. (cm)	RCD (mm)	SDW (g)	Outplanting Phase, Seedling Age & Size: Age (yrs)	Ht. (cm)	RCD (mm)	SDW (g)	Survival: Time (yrs)	%
PNb	Scarratt 1972b	OT-M	22	1.9	7.7	1:4	12	-	5.1	0.04	3	56.0	10.0	-	3	99
		OT-L	62	3.2	7.7	1:2	12	2.0	2.8	0.21	3	63.0	12.0	-	3	99
PNb	Scarratt 1973	OT-S	12	1.4	7.7	1:6	18	10.0	-	0.15	-	-	-	-	-	-
		OT-M	22	1.9	7.7	1:4	18	9.0	-	0.18	-	-	-	-	-	-
		OT-L	62	3.2	7.7	1:2	18	14.0	-	0.50	-	-	-	-	-	-
		Manuf.	157	5.1	7.7	1:2	18	22.0	-	1.40	-	-	-	-	-	-
PNb	Carlson & Nairn 1977	STY-2	35	2.4	11.0	1:5	-	-	-	-	3	102.0	19.0	-	-	-
		JPP-213	33	2.0	13.0	1:7	-	-	-	-	3	89.0	18.0	-	-	-
		JPP-408	70	3.8	7.6	1:2	-	-	-	-	3	124.0	22.0	-	-	-
		JPP-313	75	3.0	13.0	1:4	-	-	-	-	3	112.0	21.0	-	-	-
PNb	Scarratt 1981	JPP-408	70	3.8	7.6	1:2	16	10.0	2.4	1.60	-	-	-	-	3	98
		JPP-508	121	5.1	7.6	1:2	16	22.0	3.4	2.64	-	-	-	-	3	100
		JPP-608	175	6.1	7.6	1:1	16	16.0	5.1	4.22	-	-	-	-	3	100
PNb	Walker 1981	STY-2	35	2.4	11.0	1:5	-	-	-	-	5	110.0	-	-	-	-
		SL-T	500	4.2	20.0	1:4	-	-	-	-	5	140.0	-	-	-	-
PNb	Alm et al. 1982	OT-S	12	1.4	7.7	1:6	24	6.0	1.0	0.20	3	41.0	9.0	27.00	-	-
		STY-2	35	2.4	11.0	1:5	24	12.0	1.9	0.80	3	64.0	15.0	104.00	-	-
		SP-5	55	2.5	10.0	1:4	24	12.0	1.8	0.70	3	57.0	14.0	81.00	-	-
		JPP-315	88	3.0	15.0	1:5	24	17.0	1.9	0.80	3	54.0	13.0	76.00	-	-
		STY-8	115	3.8	15.0	1:4	24	11.0	2.3	1.20	3	64.0	14.0	101.00	-	-

TABLE 6. The morphological characteristics of other containerized pine seedlings found in greenhouse and outplanting studies.

Species[1]	Author & Date	Container Type	Container Size & Shape: Volume (cm³)	Diameter (cm)	Depth (cm)	Dimension (Diam/Depth)	Greenhouse Phase, Seedling Age & Size: Age (wks)	Ht. (cm)	RCD (mm)	SDW (g)	Outplanting Phase, Seedling Age & Size: Age (yrs)	Ht. (cm)	RCD (mm)	SDW (g)	Survival: Time (yrs)	%
PNca	Berger & Lysholm 1978	Manuf.	287	4.9	15.2	1:3	32	29.0	3.6	-	2	152.0	-	-	1.5	69
			504	6.5	15.2	1:2	32	31.0	4.2	-	2	173.0	-	-	1.5	77
			783	8.1	15.2	1:2	32	31.0	4.2	-	2	156.0	-	-	1.5	83
			1123	9.7	15.2	1:2	32	28.0	4.9	-	2	154.0	-	-	1.5	87
PNca	Solberg 1978	Manuf.	80	3.2	10.0	1:3	16	22.0	-	-	1	37.0	-	-	1	60
			121	3.2	15.0	1:5	16	21.0	-	-	1	37.0	-	-	1	60
			161	3.2	20.0	1:6	16	23.0	-	-	1	35.0	-	-	1	72
			189	4.9	10.0	1:2	16	20.0	-	-	1	38.0	-	-	1	80
			283	4.9	15.0	1:3	16	20.0	-	-	1	38.0	-	-	1	85
			377	4.9	20.0	1:4	16	20.0	-	-	1	37.0	-	-	1	82
			332	6.5	10.0	1:2	16	17.0	-	-	1	37.0	-	-	1	87
			498	6.5	15.0	1:2	16	17.0	-	-	1	36.0	-	-	1	88
			664	6.5	20.0	1:3	16	17.0	-	-	1	37.0	-	-	1	90
PNco	Endean 1972b	OT-S	12	1.4	7.7	1:6	16	-	-	0.69	3	-	-	0.30	-	-
		C-L	74	2.5	1.5	1:6	16	-	-	0.30	3	-	-	0.40	-	-
PNco	Endean 1973	Manuf. -tube	24	1.9	8.5	1:5	11	-	-	0.67	2	-	-	0.30	2	90
		-conical	37	-	8.9	-	11	-	-	2.04	2	-	-	1.40	2	92
PNco	Van Eerden 1974	STY-2	35	2.4	11.0	1:5	14	14.0	3.1	1.20	-	-	-			
		STY-8	115	3.8	15.0	1:4	14	13.0	3.7	2.40	-	-	-	-	-	-

[1] Note: Description of species abbreviations in Appendix I.

TABLE 6 CON'T .

TABLE 6 CON'T. The morphological characteristics of other containerized pine seedlings found in greenhouse and outplanting studies.

							Greenhouse Phase				Outplanting Phase					
			Container Size & Shape				Seedling Age & Size				Seedling Age & Size				Survival	
Species[1]	Author & Date	Container Type	Volume (cm^3)	Diameter (cm)	Depth (cm)	Dimension (Diam/Depth)	Age (wks)	Ht. (cm)	RCD (mm)	SDW (g)	Age (yrs)	Ht. (cm)	RCD (mm)	SDW (g)	Time (yrs)	%
PNco	Endean & Carlson 1975	Manuf.	10	-	-	1:3	20	-	-	0.25	-	-	-	-	-	-
			23	-	-	1:3	20	-	-	0.54	-	-	-	-	-	-
			33	-	-	1:3	20	-	-	0.72	-	-	-	-	-	-
			66	-	-	1:3	20	-	-	1.22	-	-	-	-	-	-
			131	-	-	1:3	20	-	-	1.57	-	-	-	-	-	-
			262	-	-	1:3	20	-	-	2.06	-	-	-	-	-	-
			524	-	-	1:3	20	-	-	2.44	-	-	-	-	-	-
PNco	Endean & Carlson 1975	Manuf.	All Volumes		-	1:1	20	-	-	1.39	-	-	-	-	-	
			All Volumes		-	1:3	20	-	-	1.25	-	-	-	-		
			All Volumes		-	1:6	20	-	-	1.25	-	-	-	-		
PNco	Walker 1981	STY-2	35	2.4	11.0	1:5	-	-	-	-	5	30.0	-	-		
		SL-F	40	2.1	10.0	1:4	-	-	-	-	5	60.0	-	-		
		SL-T	150	3.8	13.0	1:3	-	-	-	-	5	70.0	-	-	-	-
PNco	Gardner 1981	WB	30	2.0	11.4	1:6	12	8.0	1.8	0.89	5	72.0	-	-	5	84
		STY-2	35	2.4	11.0	1:5	12	12.0	2.3	1.55	5	82.0	-	-	5	94
PNe	Barnett & McGilvray 1981	GB	20	1.9	9.0	1:5	-	-	-	-	3	40.0	-	-	3	89
		STY-2	35	2.4	11.0	1:5	-	-	-	-	3	43.0	-	-	3	98
		SL-F	40	2.1	10.0	1:4	-	-	-	-	3	43.0	-	-	3	98
		PS	45	3.0	15.0	1:5	-	-	-	-	3	52.0	-	-	3	100
		JPP-315	88	3.0	15.2	1:5	-	-	-	-	3	46.0	-	-	3	96
PNp	Van Eerden 1978	ST-2	35	2.4	11.0	1:5	20	14.0	3.1	1.20	-	-	-	-	-	-
		ST-8	115	3.8	15.0	1:4	20	13.0	3.7	2.40	-	-	-	-		
PNp	Hite 1978	C-M	74	2.5	15.0	1:6	32	25.0	9.1	1.80	-	-	-	-		
		C-L	294	5.0	15.0	1:3	32	28.0	10.1	2.20	-	-	-	-	-	-
PNp	Van Eerden 1971 1972	OT-S	12	1.4	7.7	1:6	-	-	-	-	-	-	-	-	3	59
		OT-M	22	1.9	7.7	1:4	-	-	-	-	-	-	-	-	3	58
		WB-S	20	2.0	6.4	1:3	-	-	-	-	-	-	-	-	3	72
		WB-L	36	2.0	11.4	1:6	-	-	-	-	-	-	-	-	3	78
PNr	Davidson & Sowa 1974	OT-S	12	1.4	7.7	1:6	-	-	-	-	3	13.0	-	-	3	38
		C-S	30	1.6	15.0	1:9	-	-	-	-	3	20.0	-	-	3	20
		C-M	74	2.5	15.0	1:6	-	-	-	-	3	21.0	-	-	3	45
		JP-7	70	4.5	7.0	1:2	-	-	-	-	3	21.0	-	-	3	73
		AT	205	5.0	10.0	1:2	-	-	-	-	3	23.0	-	-	3	40
		PP	157	6.0	8.0	1:1	-	-	-	-	3	27.0	-	-	3	78
PNt	Barnett & McGilvray 1981	TP-100A	25	2.5	7.5	1:3	20	-	-	0.15	3	137.0	-	-	3	92
		TP-200	75	5.0	7.5	1:2	20	-	-	0.39	3	165.0	-	-	3	94
		JPP-315	88	3.0	15.2	1:5	20	-	-	0.20	3	158.0	-	-	3	87
PNt	Barnett & McGilvray 1981	GB	20	1.9	9.0	1:5	16	24.0	-	0.60	2	53.0	-	-	2	80
		STY-4	60	3.0	12.5	1:4	16	24.0	-	0.83	2	53.0	-	-	2	94
		TS	65	3.2	12.5	1:4	16	19.0	-	0.43	2	52.0	-	-	2	91
		TP-150	75	3.8	12.5	1:3	16	25.0	-	0.81	2	52.0	-	-	2	98
		JPP-315	88	3.0	15.0	1:5	16	22.0	-	0.55	2	48.0	-	-	2	89
		TrP-ITW	107	2.5	15.0	1:6	16	21.0	-	0.67	2	52.0	-	-	2	91

[1]Note: Description of species abbreviations in Appendix I.

No upper limits of container volume seem to exist except for caribbean pine which decreased in size when grown in containers over 60 cm^3 (Solberg, 1978). No explanation was given.

Only Endean and Carlson (1975) studied the effects of container shape on the growth of lodgepole pine in the greenhouse without including the influences from change in container volume. They found no significant differences in dry weight when the container shape was altered.

Outplanting Phase

The discontinuous nature of the field data reported in the literature makes it hard to evaluate growth trends (Table 6). Only a few publications showed a positive correlation between container volume and the height of pine seedlings after outplanting (Davidson and Sowa, 1974; Karlsson and Kovats, 1974; Gardner, 1981; Walker, 1981).

None of the studies assessed the relationship between pine seedling growth after outplanting and container shape without removing the influences from changes in container volume.

DOUGLAS FIR

Container studies with Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) have been as numerous as those with white spruce or jack pine. The data collected in greenhouse trials were more comprehensive than data collected after outplanting (Table 7).

Greenhouse Production Phase

Table 7 shows that morphological attributes varied greatly even with similar growth periods of 12 to 16 weeks. Heights varied from 9 cm (Gardner, 1981) to 39 cm (Hahn and Hutchison, 1978). Seedling dry weights varied the most from 0.5 g (Gardner, 1981) to 9.0 g (Karlsson and Kovats, 1974). It is probable that changes in container volume may be the principal cause of this variation.

In addition the growth of Douglas fir seedlings increased with container volume. All morphological attributes increased as container volume increased from 30 to 130 cm^3 (Karlsson and Kovats, 1974; Hahn and Hutchison, 1978; Arnott, 1981; Gardner, 1981).

None of the studies assessed the relationship between Douglas fir seedling growth in the greenhouse and container shape without removing the influences from changes in container volume.

Outplanting Phase

Only Karlsson and Kovats (1974) and Gardner (1981) presented growth data that was correlated with changes in container volume (Table 7). Seedling height and per cent survival significantly increased with increases in container volume from 20 to 60 cm^3. The remaining field studies could not be evaluated because of insufficient data.

None of the studies assessed the relationship between Douglas fir seedling growth after outplanting and container shape without removing the influences from changes in container volume.

HARDWOODS

In the last five years there has been a growing interest in determining a relationship between hardwood growth and container volume (Table 8). The quality of data collected in the greenhouse trials was sufficient to determine growth trends since most researchers included seedling dry weight measurements. Only seedling height and per cent survival were collected in field studies.

Greenhouse Production Phase

All hardwood studies, except one by Kellas and Edgar (1979), tested containers that were much larger than the containers used in coniferous experiments (Table 8).

Container volume may have as an important influence on the growth of hardwoods as it does on coniferous species (Table 8). All morphological attributes increased significantly as container volume increased (Kellas and Edgar, 1979; Funk et al, 1980; Ward et al, 1981). One exception to this trend occurred in a report by Elam et al (1981). They found no improvement on seedling height, root collar diameter or dry weight of a southern red oak (*Quercus falcata* var . *pagodifolia* Ell.) as container volume was increased from 500 to 1900 cm^3.

None of the studies assessed the relationship between hardwood seedling growth in the greenhouse and container shape without removing the influences from changes in container volume.

TABLE 7. The morphological characteristics of containerized Douglas Fir seedlings found in greenhouse and outplanting studies.

							Greenhouse Phase				Outplanting Phase					
			Container Size & Shape				Seedling Age & Size				Seedling Age & Size				Survival	
Species[1]	Author & Date	Container Type	Volume (cm^3)	Diameter (cm)	Depth (cm)	Dimension (Diam/Depth)	Age (wks)	Ht. (cm)	RCD (mm)	SDW (g)	Age (yrs)	Ht. (cm)	RCD (mm)	SDW (g)	Time (yrs)	%
PSm	Karlson & Kovats 1974	STY-2	35	2.4	11.0	1:5	16	10.0	1.5	2.50	2	23.0	30.5	-	1	65
		STY-4	60	3.0	12.5	1:4	16	15.0	2.0	9.00	2	32.0	-	-	1	95
PSm	Arnott 1974	WB-L	36	2.0	11.4	1:6					3	30.0			3	77
PSm	Hahn & Hutchison 1978	MP-1	58	3.3	9.0	1:3	16	25.0	2.6	-		-	-	-	3	59
		MP-2	67	3.3	12.0	1:4	16	33.0	3.3	-		-	-	-	3	-
		MP-4	136	4.0	16.4	1:4	16	39.0	4.2	-		-	-	-	3	76
PSm	Van Eerden 1971 1972	OT-S	12	1.4	7.7	1:6	-	-	-	-	-	-	-	-	3	51
		OT-M	22	1.9	7.7	1:4	-	-	-	-	-	-	-	-	3	-
		WB-S	20	2.0	6.4	1:3	-	-	-	-	-	-	-	-	3	76
		WB-L	36	2.0	11.4	1:6	-	-	-	-	-	-	-	-	3	58
PSm	Arnott 1981	WB-L	36	2.0	11.4	1:6	16	11.0	-	0.80	5	45.0	-	-	5	78
		STY	-	-	-	-	16	12.0	-	0.99	5	45.0	-	-	5	55
PSm	Gardner 1981	WB-S	20	2.0	6.4	1:3	12	9.0	1.6	0.50	5	26.0	-	-	5	65
		STY-2	35	2.4	11.0	1:5	12	19.0	2.1	1.30	5	37.0	-	-	5	80

TABLE 8. The morphological characteristics of containerized hardwood seedlings found in greenhouse and outplanting studies.

							Greenhouse Phase				Outplanting Phase					
			Container Size & Shape				Seedling Age & Size				Seedling Age & Size				Survival	
Species[1]	Author & Date	Container Type	Volume (cm^3)	Diameter (cm)	Depth (cm)	Dimension (Diam/Depth)	Age (wks)	Ht. (cm)	RCD (mm)	SDW (g)	Age (yrs)	Ht. (cm)	RCD (mm)	SDW (g)	Time (yrs)	%
ACsc	Ward et al 1981	Manuf.	1000	-	-	-	20	21.0	3.4	6.10	-	-	-	-	-	-
			4500	-	-	-	20	105.0	6.2	34.00	-	-	-	-	-	-
			9000	-	-	-	20	135.0	6.4	41.60	-	-	-	-	-	-
EUr	Kellas & Edgar 1979	JP-522	33	3.5	5.1	1:2	32	5.8	-	-	1	104.0	-	-	1	75
		STY-2	35	2.4	11.0	1:5	32	5.6	-	-	1	139.0	-	-	1	73
		JP-515	61	4.7	5.1	1:1	32	7.6	-	-	1	136.0	-	-	1	85
		JPP-415.5	70	3.8	7.6	1:2	32	7.5	-	-	1	122.0	-	-	1	80
		STY-8	115	3.8	15.0	1:4	32	9.5	-	-	1	140.0	-	-	1	86
		JPP-415	140	3.8	15.2	1:4	32	11.6	-	-	1	137.0	-	-	1	87
[illegible]n	Funk et al 1980	Manuf.	1150	13.0	8.7	1:1	-	-	-	7.00	-	-	-	-	-	-
			3450	10.0	61.0	1:6	-	-	-	16.60	-	-	-	-	-	-
			10350	15.0	61.0	1:4		-	-	28.40	-	-	-	-	-	-
JUn	Goodwin et al 1981	SL-T	500	4.2	20.5	1:4		-	-	-	4	225.0	-	-	3.5	90
		SL-45	700	5.7	25.0	1:4					4	201.0	-		3.5	83
	Elam et al 1981	Manuf.	500	-	-	-	12	21.0	4.2	2.70	4	58.0	13.8	-	3	77
			900	-	-	-	12	22.0	4.3	3.10	4	80.0	19.8	-	3	92
			1900	-	-	-	12	23.0	4.9	3.50	4	60.0	13.9	-	3	77

[1]Note: Description of species abbreviations in Appendix I.

Outplanting Phase

There were no reports of significant improvements in seedling heights or per cent survival of hardwoods produced in different size containers (Table 8). It is possible that the rapid growth of hardwoods may override any influence of the original soil volume. This is not the case for coniferous species because of the slower root development.

Maximum limits of container volume appear to be present. The largest containers in several reports produced a smaller seedling after four growing seasons (Goodwin et al, 1981; Elam et al, 1981). No explanation was given in the literature.

None of the studies assessed the relationship between hardwood seedling growth after outplanting and container shape without removing the influences from changes in container volume.

AGRICULTURAL, ORNAMENTAL AND EXOTIC CROPS

The effects of container volume on plant growth was first investigated in agricultural crops in the early 1960's (Table 9). Twenty years later ornamental growers became interested in the influences of container volume and shape on plant growth. All studies measured only plant dry weight since height and root collar mesurements were not applicable to these species. No studies were continued from the greenhouse into field trials.

Greenhouse Production Phase

All agricultural crops tested were positively affected by container volume increases (Table 9). The plant dry weight significantly increased as the container volume increased (Baker and Woodruff, 1961; Larsen and Sutton, 1963; Cornforth, 1968; Kratky et al, 1982).

None of the studies assessed the relationship between seedling growth and container shape without removing the influences from changes in container volume.

Only two studies tested the effect container volume had on the dry weight of ornamental plants (Table 10). A growth trend was present in only one study by (Biran and Elliassaf, 1980b). They found that as the container volume increased there was a significant increase in plant dry weight.

Another study by Biran and Elliassaf (1980a) tested the influences of container shape on growth while omitting any influences from container volume changes (Table 10). Biran and Elliassaf (1980a) discovered that the growth and distribution of roots were drastically affected by container shape. The growth of shallow root system species was stimulated in shallow, wide containers but was restricted in deep, narrow containers. The growth of deep root system species behaved in a converse manner.

CONCLUSIONS

The literature shows that the data on the relationship between container volume and shape on seedling growth was very discontinuous because many authors did not incorporate the results of both greenhouse and field trials. Also many authors omitted

TABLE 9. The morphological characteristics of containerized agricultural crops found in greenhouse studies.

							Greenhouse Phase				Outplanting Phase					
			Container Size & Shape				Seedling Age & Size				Seedling Age & Size				Survival	
Species[1]	Author & Date	Container Type	Volume (cm^3)	Diameter (cm)	Depth (cm)	Dimension (Diam/Depth)	Age (wks)	Ht. (cm)	RCD (mm)	SDW (g)	Age (yrs)	Ht. (cm)	RCD (mm)	SDW (g)	Time (yrs)	%
BRp	Kratky	Manuf.	31	2.5	6.4	1:3	6	-	-	5.40	-	-	-	-	-	-
	et al		71	3.7	6.4	1:2	6	-	-	9.10	-	-	-	-	-	-
	1982		126	5.0	6.4	1:1	6	-	-	15.40	-	-	-	-	-	-
			283	7.5	6.4	1:1	6	-	-	30.10	-	-	-	-	-	-
AVs	Cornforth	Manuf.	1390	-	-	-	6	-	-	5.80	-	-	-	-	-	-
	1968		2780	-	-	-	6	-	-	6.10	-	-	-	-	-	-
			5560	-	-	-	6	-	-	7.40	-	-	-	-	-	-
LOp	Larsen &	Manuf.	664	13.0	5.0	1:1	-	-	-	6.60	-	-	-	-	-	-
	Sutton		1327	13.0	10.0	1:1	-	-	-	9.25	-	-	-	-	-	-
	1963		2655	13.0	20.0	1:2	-	-	-	13.40	-	-	-	-	-	-
			5310	13.0	40.0	1:3	-	-	-	21.10	-	-	-	-	-	-
ZEm	Baker &	Manuf.	500	-	-	-	5	-	-	39.00	-	-	-	-	-	-
	Woodruff		1000	-	-	-	5	-	-	66.00	-	-	-	-	-	-
	1962		2000	-	-	-	5	-	-	79.00	-	-	-	-	-	-
			4000	-	-		5	-	-	110.00	-	-	-	-	-	-
			8000	-	-	-	5	-	-	130.00	-	-	-	-	-	-
			16000	-	-	-	5	-	-	155.00	-	-	-	-	-	-

TABLE 10. The morphological characteristics of containerized ornamental and exotic plants found in greenhouse studies.

							Greenhouse Phase				Outplanting Phase					
			Container Size & Shape				Seedling Age & Size				Seedling Age & Size				Survival	
Species[1]	Author & Date	Container Type	Volume (cm^3)	Diameter (cm)	Depth (cm)	Dimension (Diam/Depth)	Age (wks)	Ht. (cm)	RCD (mm)	SDW (g)	Age (yrs)	Ht. (cm)	RCD (mm)	SDW (g)	Time (yrs)	%
DOv	Biran &	Manuf.	1000	-	-	-	34	-	-	231.00	-	-	-	-	-	-
	Elliassaf		2500	-	-	-	34	-	-	441.00	-	-	-	-	-	-
	1980b		10000	-	-	-	34	-	-	1386.00	-	-	-	-	-	-
¯Ir	Biran &	Manuf.	21000	54.0	9.2	1:1	24	-	-	2944.00	-	-	-	-	-	-
	Eliassaf		21000	28.5	33.0	1:1	24	-	-	2923.00	-	-	-	-	-	-
	1980a		21000	15.0	119.0	1:8	24	-	-	1878.00	-	-	-	-	-	
FIr	Biran &	Manuf.	5000	-	-	-	40	-	-	931.00	-	-	-	.	-	
	Eliassaf		21000				40	-	-	3365.00	-					
	1980b															
·INv	Goodale &	Manuf.	2245				32	-	-	103.00	-	-	-	-	-	-
	Whitcomb		3245				32	-	-	104.00	-	-	-	-	-	-
	1980		4408				32	-	-	121.00	-	-	-	-	-	-
			5768	-	-	-	32	-	-	116.00	-	-	-	-	-	-
PTl	Biran &	Manuf.	2500	28.5	4.0	1:1	24	-	-	310.00	-	-	-	-	-	-
	Eliassaf		2500	14.5	15.1	1:1	24	-	-	475.00	-	-	-	-	-	-
	1980a		2500	7.5	56.6	1:8	24	-	-	535.00	-	-	-	-	-	-
¯Tl	Biran &	Manuf.	1000	-	-	-	43	-	-	334.00	-	-	-	.	-	-
	Eliassaf		2500				43	-	-	526.00	-					-
	1980b															

[1]Note: Description of species abbreviations in Appendix I.

measurements of growth such as dry weight. These omissions make it difficult to assess the relationship between container volume and shape on seedling growth.

There was considerable variation in the growth data recorded for most species and especially for white spruce, black spruce, jack pine and Douglas fir. Most of this variation appears to be caused by differences in the growth environments and in the cultural treatments used in each study. The principal environmental factor influencing growth appears to be the change in container volume.

In general, seedling growth during the greenhouse production phase increased with increasing container volume between lower and upper volume limits. For many species, such as white spruce, jack pine and lodgepole pine, seedling growth was restricted and was generally substandard in small container volumes less than 30 cm^3 (Scarratt, 1972b, 1972c, 1973; Endean, 1973; Endean and Carlson, 1975; Carlson and Endean, 1976; Gardner, 1981; Alm et al, 1982). Furuta (1976) describes this growth restriction as 'the pot-binding phenomenon'. Thus 30 cm^3 may be considered to be the lower volume limit. Upper volume limits may also exist for white spruce, black spruce, jack pine and caribbean pine. The limits vary depending on the innate growth pattern of each species but generally ranged from 90 to 120 cm^3(Scarratt, 1973, 1981; Carlson and Endean, 1976; Alm et al, 1982; Solberg, 1978). The excess water not used by seedling growing in oversized containers may produce a water-logged environment that impairs aeration. This in turn reduces photosynthesis, translocation and growth (Kramer and Kozlowski, 1979: 188-220 ; Biran and Elliassaf, 1980a).

Only three studies attempted to evaluate the relationship between seedling growth and changes in container shape while removing influences from changes in container volume

(Endean and Carlson, 1975; Carlson and Endean, 1976; Biran and Elliassaf, 1980a). White spruce and a few ornamental species responded to container shape. In general, species with shallow root systems grew better in shallow, wide containers and species with deep root systems grew better in long, narrow containers. Restricting the natural configuration of a root system by mismatching the container shape may be detrimental to nutrient and water uptake and thus reduce growth.

Growth trends were more difficult to analyse in field trials since poor growth indicators such as height and per cent survival were mainly recorded. However, the literature did show that seedling growth after outplanting increased with an increase in container volume for white spruce, black spruce, norway spruce, jack pine, and Douglas fir (Scarratt, 1972b; Roller, 1976, 1977; Karlsson and Kovats, 1974; Gardner, 1981; McMinn, 1981; Walker, 1981; Alm et al, 1982).

None of the outplanting studies attempted to assess the effect container shape had on seedling growth without removing the influences from change in container volume.

MATERIALS AND METHODS

GREENHOUSE PRODUCTION PHASE

Experimental Design

The greenhouse study was established as a 4 x 3 factorial experiment in a randomized complete-block design with sub-sampling (Steel and Torrie, 1960: 142-145). The 12 treatments were made up of containers of four volumes (45, 90, 180, 360 cm^3) and three diameter/depth dimensions or shapes (1:2, 1:3, 1:4) for each of the volumes. The open circles in Figure 1 illustrate the distribution of container sizes and shapes. The treatments were replicated 4 times. Each of the 48 treatment-replication combinations was initially designed to contain 40 seedlings. Fifteen of these seedlings were sampled destructively in the greenhouse production phase.

Container Construction

The containers, used to grow the black spruce stock in, were manufactured from clear acrylic plastic tubing. The tubing size ranges needed in this study was only available in nine diameter sizes (2.54 cm, 2.86 cm, 3.18 cm, 3.49 cm, 3.81 cm, 4.13 cm, 4.76 cm, 5.40 cm and 6.03 cm). With tubing in this size range, containers of four volumes could be constructed at each of the three diameter/depth dimensions (Figures 2 and 3). The 12 container sizes did not quite match up with the line intercepts of size and shape owing to the limited sizes of tubing available (Figure 1). Table 11 gives the dimensions of the 12 experimental containers and the abbreviated names of commercial containers

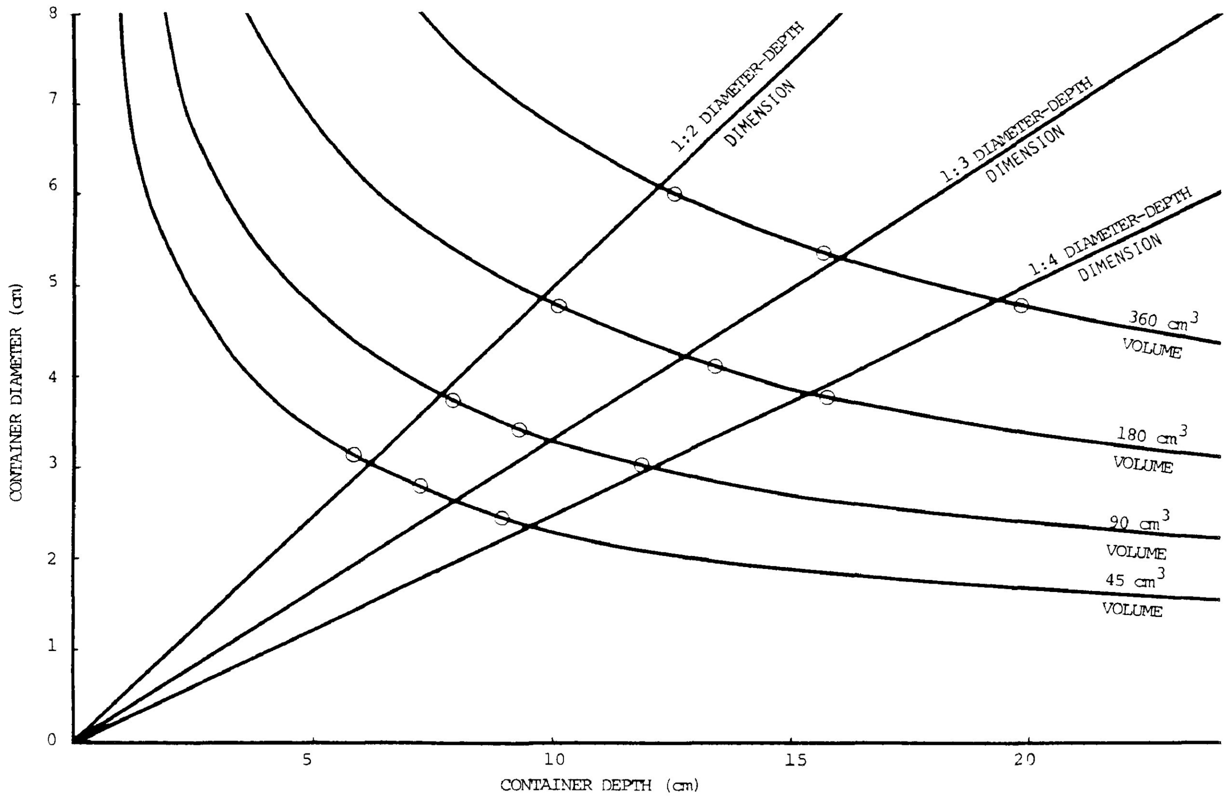

Figure 1. Container volume and diameter/depth dimensions of the 12 container treatments.

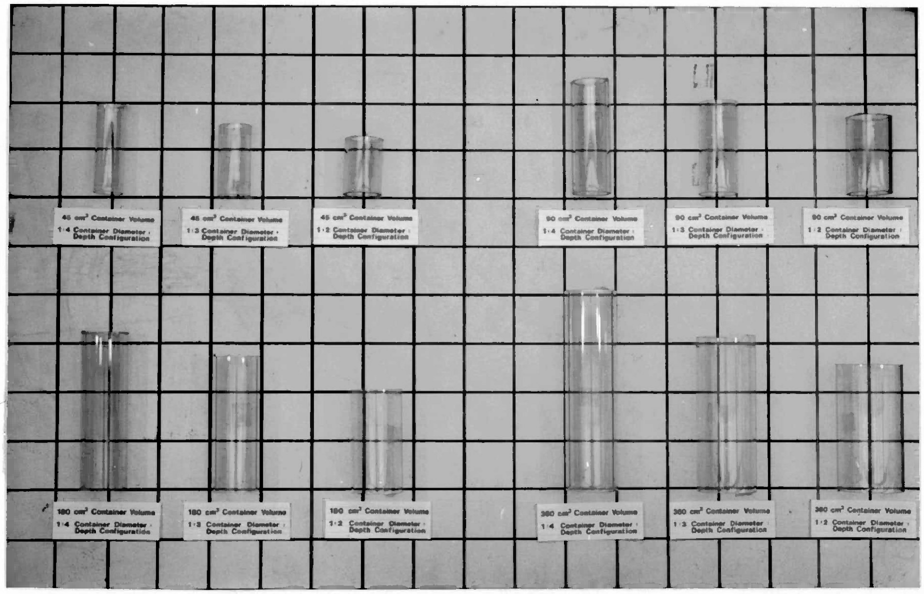

Figure 2. Side view showing 12 acrylic container treatments

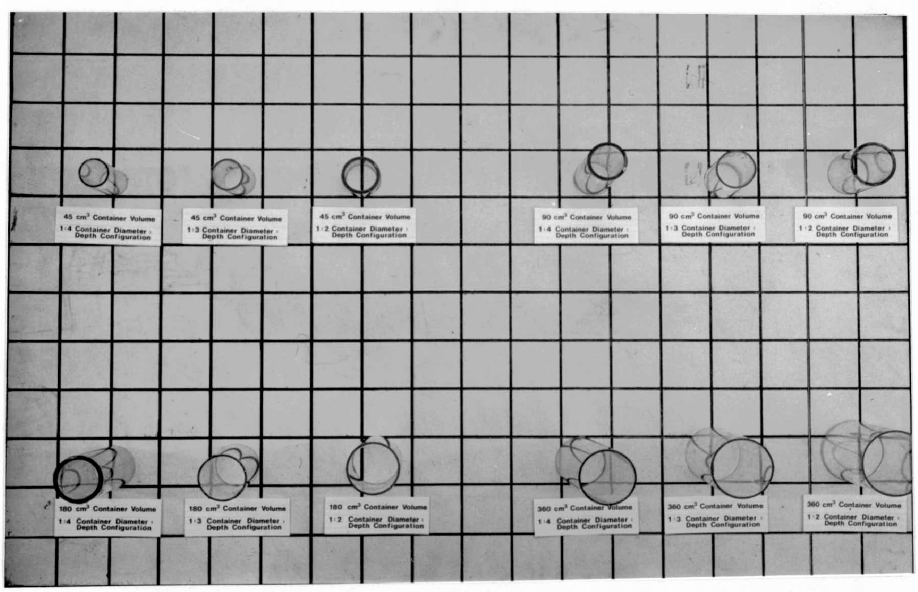

Figure 3. Top view showing 12 acrylic container treatments

TABLE 11. Dimensions of the 12 experimental containers and the abbreviated names of commercial containers of similar size and shape.

Container Volume (cm^3)	Container Diameter / Depth Configuration (cm / cm) 1:2	1:3	1:4
45	3.18 / 5.80 JP-522	2.86 / 7.10 MP-1 OT-L	2.54 / 9.00 SL-F, SL-5 STY-4, TS
90	3.81 / 7.90 JPP-408, JPP-508 JP-7, TP-200	3.49 / 9.40 TP-150	3.18 / 11.40 JPP-313, MP-2 STY-8
180	4.76 / 10.10 AT	4.13 / 13.50 SL-H	3.81 / 15.80 JPP-415, MP-4
360	6.03 / 12.60 C-L	5.40 / 15.70 STY-20	4.76 / 20.2 SL-T

See Table 1 for commercial container description.

of similar size and shape.

After the tubing was cut to the proper lengths, a 12 cm square piece of black nylon screen was fitted over one end of each container and held secure with a heavy elastic band. The screening was used to contain the growing medium, provide proper drainage and air prune emerging roots (Figure 4).

Growing Medium

A growing medium of the following mixture was hand filled to within 1 cm of the top of each container.

1) Sunshine, horticultural peat moss - 60 per cent by volume.

2) Grace medium size horticultural vermiculite - 20 per cent by volume.

3) Grace horticultural perlite - 20 per cent by volume.

The following additives were then incorporated into the growing medium according to specifications recommended by the soils laboratory at Guelph University.

1) Calcium carbonate - 5.12 g/l

2) Superphosphate (0-50-0,Plant Products) - 1.12 g/l

3) Chelated trace elements (Plant Products) - 0.28 g/l

Container Support Stands

Eight 1.2 x 2.4 m sheets of 1.3 cm thick fir plywood were used to make the supports for the containers. Each of the four replications were randomly located in two

1.2 x 2.4 m plywood sheets. In each replication forty circular holes were cut out on 10 cm centres for each of the 12 treatments tested. An intra-tree distance of 10 cm ensured that all treatments were grown at the same spacing. The plywood sheets were raised off the greenhouse bench with 30 cm high supports. This allowed the containers to hang down below the plywood surface and it kept all containers at the same level, regardless of their depth (Figure 4). This ensured that the seedlings received the same light intensity during the growing phase(Figure 5).

The 12 container types, filled with growing medium, were then placed in their designated treatment-replications in groups of 40's. A heavy elastic band was placed around the top edge of each container to prevent them from slipping down through the holes. Black polyethelene sheeting was stapled over the open sides of the stands to prevent light from hitting the container walls under the plywood sheets. This was necessary since the containers were clear and translucent, and direct light could heat up the growing medium, stimulate the growth of mould and affect root growth (Figure 5).

Environmental Conditions and Cultural Treatments.

Germination Phase

The growing medium in all containers was soaked with water and allowed to drain for 48 hours before the seed was sown. Black spruce seed from the Thunder Bay Forest Station was hand sown onto the growing medium of all 1,920 containers on February 4th, 1983. The containers were then watered regularly, and maintained fully moist (at,

Figure 4. Black nylon screen over the bottoms of the acrylic plastic tubing

Figure 5. Container support stands in the greenhouse production phase

or close to, field capacity) to prevent the seeds from drying out during germination. Clear polyethelene sheeting was placed over the tops of the containers to prevent moisture loss, increase moisture content and surface temperature.

The greenhouse temperature was maintained at 20°C day and 15°C night. The humidity level was raised to 60 per cent with the use of sprinkler hoses under the benches. The hoses automatically turned on five minutes every half hour during the day. At night they were turned off because the humidity was greater than 60 per cent between 8:00 p.m. and 6:00 a.m. A shade cloth with 50 per cent light transmission was strung up over the study to reduce the heat load under the polyethelene sheeting.

Two weeks after seeding, on February 19, 1983, germination was complete and only 10 per cent of the containers were empty. To make sure that all containers were filled, extra seedlings from adjacent containers were hand transplanted into the empty ones.

Growth Phase

After the transplanting was complete, high intensity sodium lights (Lumiponic-400 W) were turned on to maintain a 18 hour photoperiod and a continuous feed fertilization programme was started. The seedlings were watered continuously with 200 ppm (based on nitrogen) of Plant Products fertilizer 20-20-20. The leachate was measured at every watering with a salts meter (Plant Products Model DP-05) to make sure the salts in the growing medium ranged between 1000 to 1500 microhmos. If the salt readings fell below this range more fertilizer was applied and if the readings went above this range the seedlings were leached with pure water.

On March 30, 1983 extra seedlings were thinned out so that one seedling remained in each container. This was done before lateral root development was too extensive so that minimal damage occurred to the remaining seedlings. Twelve weeks after germination, on May 15th, 1983, the growth phase was complete and the seedlings were then hardened off in preparation for field outplanting.

Hardening Off Phase

On May 15th, 1983 the artificial lighting was turned off and the greenhouse temperature was gradually cooled down over a period of two weeks to day and night temperatures respectively of 10°C and 6°C. The fertilizer was changed to a high phosphorous fertilizer 15-30-15 at 200 ppm (based on nitrogen) to promote root development.

The seedlings to be used in the greenhouse and field trials were randomly chosen and tagged. Each tag had the tree number, treatment number and replication number on it for individual identification.

Measurement of Seedling Morphological Quality

Sixteen weeks after seeding, on May 27th, 1983, 15 seedlings were harvested from each of the 12 container size treatments in all four replications. Photographs were taken with a Canon AE1 camera and macro-zoom lens of the following:

1) The experiment in the greenhouse,

2) An average height seedling from each of the twelve container treatments,

a) in the container,

b) out of the container with washed root systems.

Four attributes of the morphological quality of the seedlings were measured:

1) Height from the root collar to top of terminal shoot axis (cm),

2) Root collar diameter (mm),

3) Top dry weight (g),

4) Root dry weight (g).

The seedling heights were measured in cm to 0.1 cm accuracy with a ruler. The root collar diameters were measurd to a 0.1 mm accuracy with a caliper.

After the heights and root collar diameters were measured each seedling was carefully washed in water to remove the growing medium from the root system. Each seedling was cut in two at the root collar and the top and roots were placed in separate labelled paper bags. All bags were then dried in an oven at 65°C for 48 hours. The tops and roots were then weighed individually on an electronic digital balance (Sartorius, Model MP1212). The weights were recorded in g to the nearest 0.001 g.

In addition, Dickson's Seedling Quality Index (Qix) equation was used to compute Qix values from the above morphological characteristics of each seedling (Dickson et al, 1960).

$$Qix = \frac{\text{Seedling total dry weight (g)}}{\dfrac{\text{Height (cm)}}{\text{Root collar diameter (mm)}} + \dfrac{\text{Top dry weight (g)}}{\text{Root dry weight (g)}}}$$

Data Analyses

In order to test the hypotheses of no differences between the 12 container treatments, the variations in the data for each morphological characteristic and the quality index was independently analysed as a 3 x 4 factorial experiment in a randomized complete block design. If the analysis of variance (ANOVA) showed significant differences between the treatment means, Student-Newman-Keul tests were conducted to evaluate the significance of the differences between individual treatments (Steel and Torrie, 1960: 110-111).

Using the natural logarithmic transformation of container volume (X_1), container diameter (X_2), and container depth (X_3) as independent variables, relationships were established between each of the following logarithmically transformed dependent variables:

1) Seedling height (Ht),

2) Root collar diameter (RCD),

3) Top dry weight (TDW),

4) Root dry weight (RDW),

5) Total dry weight (TOTDW),

6) Dickson's seedling quality index value (Qix),

The general form of the multiple linear regression (MLR) equation fitted was;

$$\text{Ln } Y = a + b_1 \text{ Ln } X_1 - b_2X_2 - b_3X_3 \qquad (1)$$

where: Ln Y = Natural logarithmic transformation of the morphological characteristics and Qix values

$\text{Ln}X_1$ = Natural logarithmic transformation of container volume (cm^3)

X_2 = Container diameter (cm)

X_3 = Container depth (cm)

Equation 1 was rewritten to solve for Y as follows:

$$Y = \frac{e^{a + b_1 (\text{Ln}X_1)}}{e^{b_2(X_2) + b_3 (X_3)}} \qquad (2)$$

Since the patterns of residuals in all the greenhouse data were abnormal, the Y values were transformed logarithmically to produce normal patterns of residuals in order to satisfy the assumptions underlying multiple regression models (Appendix II).

This general form of the MLR equation was used to determine the best estimate for the population means. The estimates were adjusted by a method described by Baskerville (1971) to remove a systematic error produced from logarithmic transformations. Student's t tests were conducted on the standardized regression b-coefficients in the MLR equations to evaluate the effects each varible had on the Y values.

The regression equations were used to construct response surfaces. However these equations produced four dimensional arrays which were impossible to illustrate. Therefore the varibles container diameter (X_2) and depth (X_3) were treated as a ratio and three dimensional response surfaces were constructed. These response surfaces helped to determine the optimum range of container size and shapes necessary to produce high quality black spruce container seedlings in the greenhouse.

FIELD OUTPLANTING PHASE

Study Area

Location and Climate

The field outplanting site was located on Abitibi-Price private land, block (3, 120 Km northwest of Thunder Bay near Raith, Ontario (Figure 6). The planting site was within the B9 Section of the Boreal Forest Region (Rowe, 1972) at latitude 48 55′N, longitude 89 55′W .

The mean growing season length is 150 days (based on a mean monthly temperature above $5^{\circ}C$) and the mean annual precipitation is 750 mm, with 407 mm falling during the growing season (Environ. Can., 1980).

Topography and Soil Characteristics

The area is a typical sandy outwash plain. The soil is composed of waterlain sands, grits and gravels and is greater than one metre in depth. The planting site was a flat, terraced inactive flood plain with inter-banded stratified materials (Zoltai,1965). Well rounded water lapped boulders were found throughout the soil profile (Figure 7).

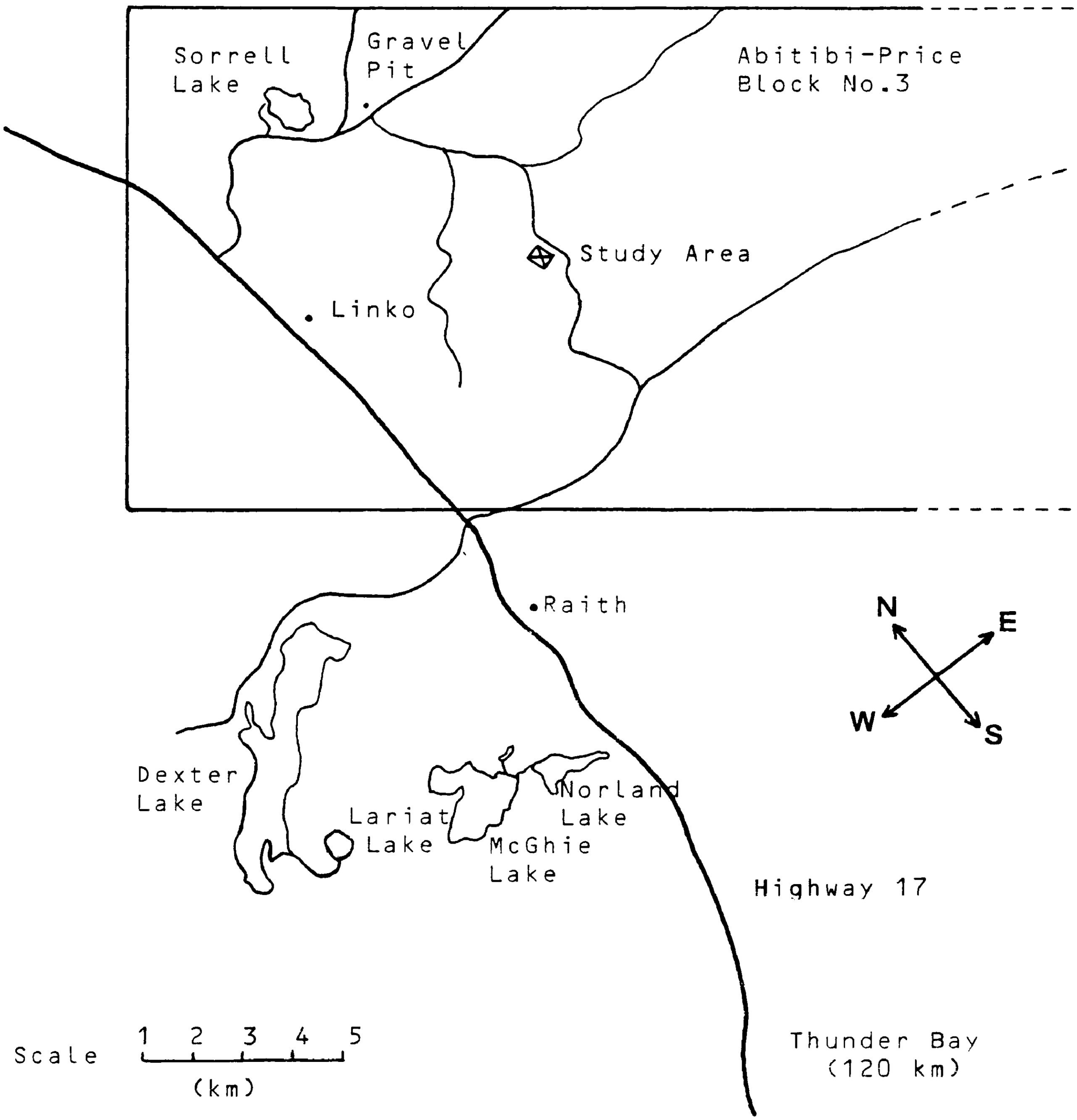

Figure 6. Location of field outplanting study area.

Experimental Design

The field study was established as a 4 x 3 factorial experiment in a randomized complete-block design with sub sampling (Steel and Torrie, 1960: 142-145). The 12 treatments were made up of containers of four volumes (45, 90, 180, 360 cm^3) and three diameter/depth configurations (1:2, 1:3, 1:4) for each of the volumes. The treatments were replicated three times. Each of the 36 treatment-replication combinations initially contained 12 seedlings.

Plantation Establishment

The planting site was site prepared with a TTS Disc Trencher (Myles, 1978; Smith, 1980) in 1982. In the spring of 1983 three 0.72 ha blocks were randomly located on the planting site (Figure 8). Each block was 24x30 m in size and was composed of 12 randomly located treatment plots which were staked at the corners. Each treatment plot was 6x10 m in size and contained three TTS trenches (Figure 9).

On June 19th, 1983 the seedlings produced in the greenhouse trial which had been tagged for field planting, were measured for initial field height and root collar diameters in the lab. In the field, the acrylic plastic containers were removed before the seedlings were planted on the plots with tree planting shovels. Within each treatment block seedlings were planted two metres apart. Care was taken in properly selecting each microsite and in repacking the soil around each seedling's roots (Figure 10).

Figure 7. Soil profile at field outplanting site

Figure 8. Disc trench scarification at field outplanting site

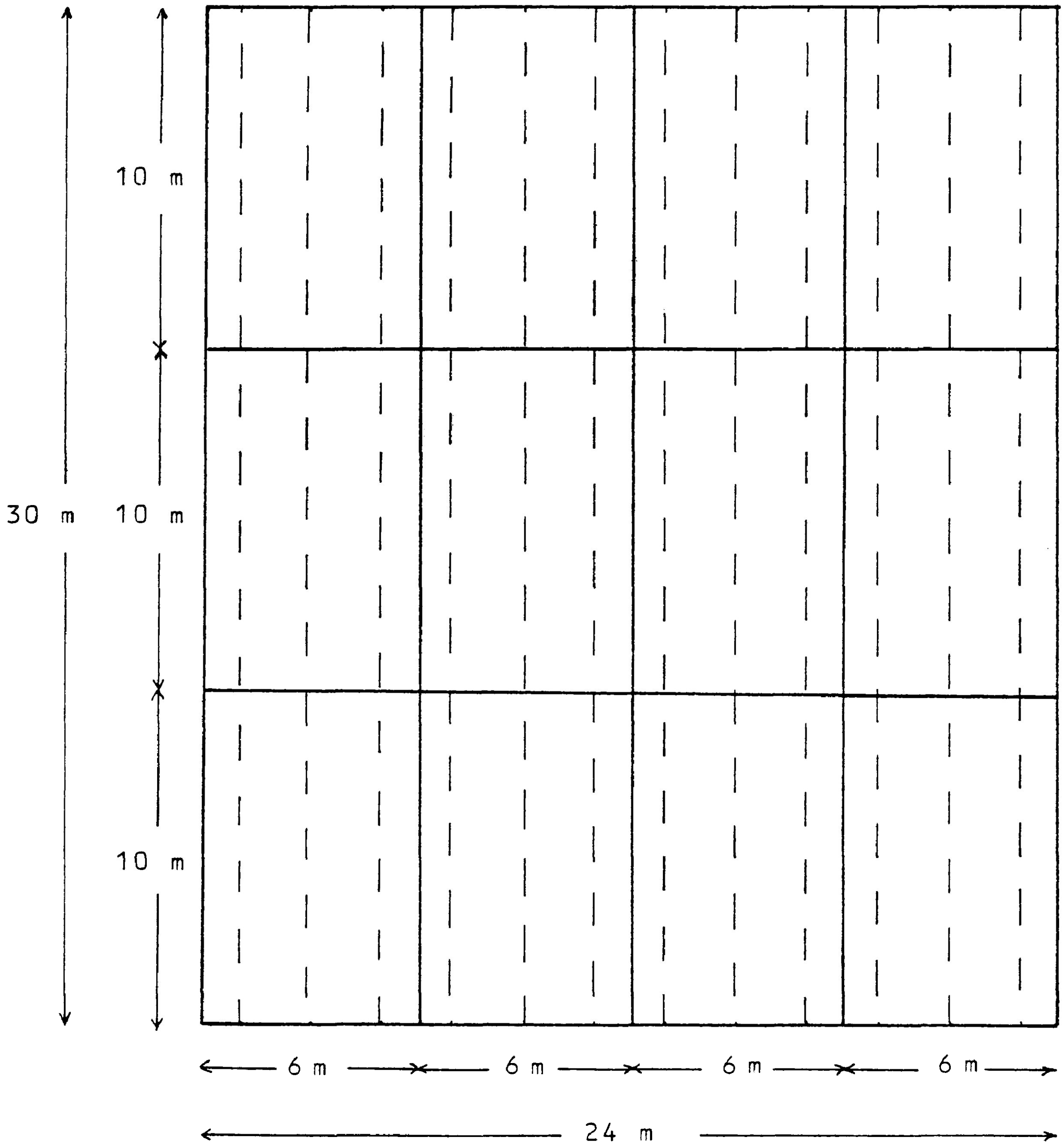

Figure 9. Planting design of the 12 container treatments within each block.

Figure 10. Black spruce container seedling outolanted in disc trench

Measurement of Seedling Morphological Quality

On September 23rd, 1983, twelve seedlings were harvested from each of the 12 container size treatments in all three replications. A spade was used to lift the seedlings carefully without damaging the root systems. Excess soil and other roots were carefully removed from the seedlings root systems at the planting site. Of the 432 seedlings outplanted, 25 were either severely damaged or killed by grasshoppers (*Camnula pellucida*). These seedlings were omitted from the study. The surviving seedlings of each treatment were packed into plastic bags and transported to a cooler where they were stored at 5°C before measurements were taken.

Photographs were taken with a Canon AE1 camera and macro-zoom lens of the:

1) Plantation site,
2) Soil profile,
3) Seedlings planted,
4) An average height seedling for each of the twelve container treatments,
    a) with unwashed root systems,
    b) with washed root systems.

Four attributes of morphological quality of the seedlings were measured:

1) Height from the root collar to top of terminal leader (cm),
2) Root collar diameter (mm),
3) Top dry weight (g),
4) Root dry weight (g).

The seedling heights were measured in cm to 0.1 cm accuracy with a ruler. The root collar diameters were measured to 0.1 mm accuracy with a caliper.

After the heights and root collar diameters were measured each seedling was carefully washed in water to remove the growing medium, soil and other roots from the seedlings root systems. Each seedling was cut in two, at the root collar and the top and roots were placed in separate labelled paper bags. All bags were then dried in an oven at 65°C for 48 hours. The tops and roots were then weighed individually on an electronic digital balance (Sartorius, Model MP1212). The weights were recorded in g to the nearest 0.001 g.

A method developed by Yates (1933) was used to compute estimates of height, root collar diameter, top, root and total dry weight of the 25 missing seedlings. These estimates were incorporated into further data analyses (Steel and Torrie, 1960: 139-141).

In addition, Dickson's Seedling Quality Index (Qix) equation was used to compute Qix values from the above morphological characteristics of each seedling (Dickson et al, 1960).

$$Qix = \frac{\text{Seedling total dry weight (g)}}{\dfrac{\text{Height (cm)}}{\text{Root collar diameter (mm)}} + \dfrac{\text{Top dry weight (g)}}{\text{Root dry weight (g)}}}$$

Data Analyses

In the outplanting phase, the hypothesis of no differences between treatments was tested by making use of the variable initial field height x root collar diameter squared (ie: X= Ht x RCD2) as covariate. Again, the variation of each morphological characteristic and quality index (Qix) was analysed as a 4 x 3 factorial experiment in a randomized complete-block design with X as the covariate and with sub sampling. If the analyses of covariance (ANOCA) did not increase the accuracy of the experiment over analyses of variance (ANOVA), as described by Finney (1946), then the results of the ANOCAs were discarded in favour of the ANOVAs. If the ANOCAs or ANOVAs showed that there were significant differences between the treatment means, Student-Newman-Keul tests were conducted to evaluate the significance of the differences between individual treatments (Steel and Torrie, 1960: 110-111).

Using the natural logarithmic transformation of container volume (X_1), container diameter (X_2), and container depth (X_3) as independent variables, relationships were established between each of the following logarithmically transformed dependent variables:

1) Seedling height (Ht),

2) Root collar diameter (RCD),

3) Top dry weight (TDW),

4) Root dry weight (RDW),

5) Total dry weight (TOTDW),

6) Dicksons seedling quality index value (Qix),

The general form of the MLR equation fitted is equation (1) given on page 38. The purpose of fitting this function for the six dependent variables obtained from the outplanting trial was the same as for the greenhouse trial.

RESULTS

GREENHOUSE PRODUCTION PHASE

Analyses of variance (ANOVA), Student-Newman-Keul (SNK) tests were conducted and Multiple Linear Regressions (MLR) equations were fitted for all morphological characteristics and seedling quality indices after 16 weeks in the greenhouse. The average black spruce seedling grown in the 12 container treatments are shown in Figure 11. From the analyses the following three general trends in the greenhouse data were observed:

1) The ANOVAs showed that there were highly significant differences ($P^1 < 0.001$) between the seedlings grown in the 12 container treatments and that the main effect of container volume exclusively influenced seedling growth (Table 12).

2) The SNK tests also showed that the differences in seedling growth were largely caused by the influence of container volume. Container dimension had no influence on the seedlings. The SNK tests showed that there was more variation in dry weight than in height and root collar diameters (Appendix III).

3) The MLRs showed that the differences in seedling growth in the greenhouse were caused by the influence of container volume and depth (Table 13). The MLR equations for the morphological characteristics and Qix values are presented in Table 14.

[1] Note: The probability of F (variance ratio) being greater than the calculated F is less than 1 chances in 1,000. $(P(F > Fc) < 0.001)$

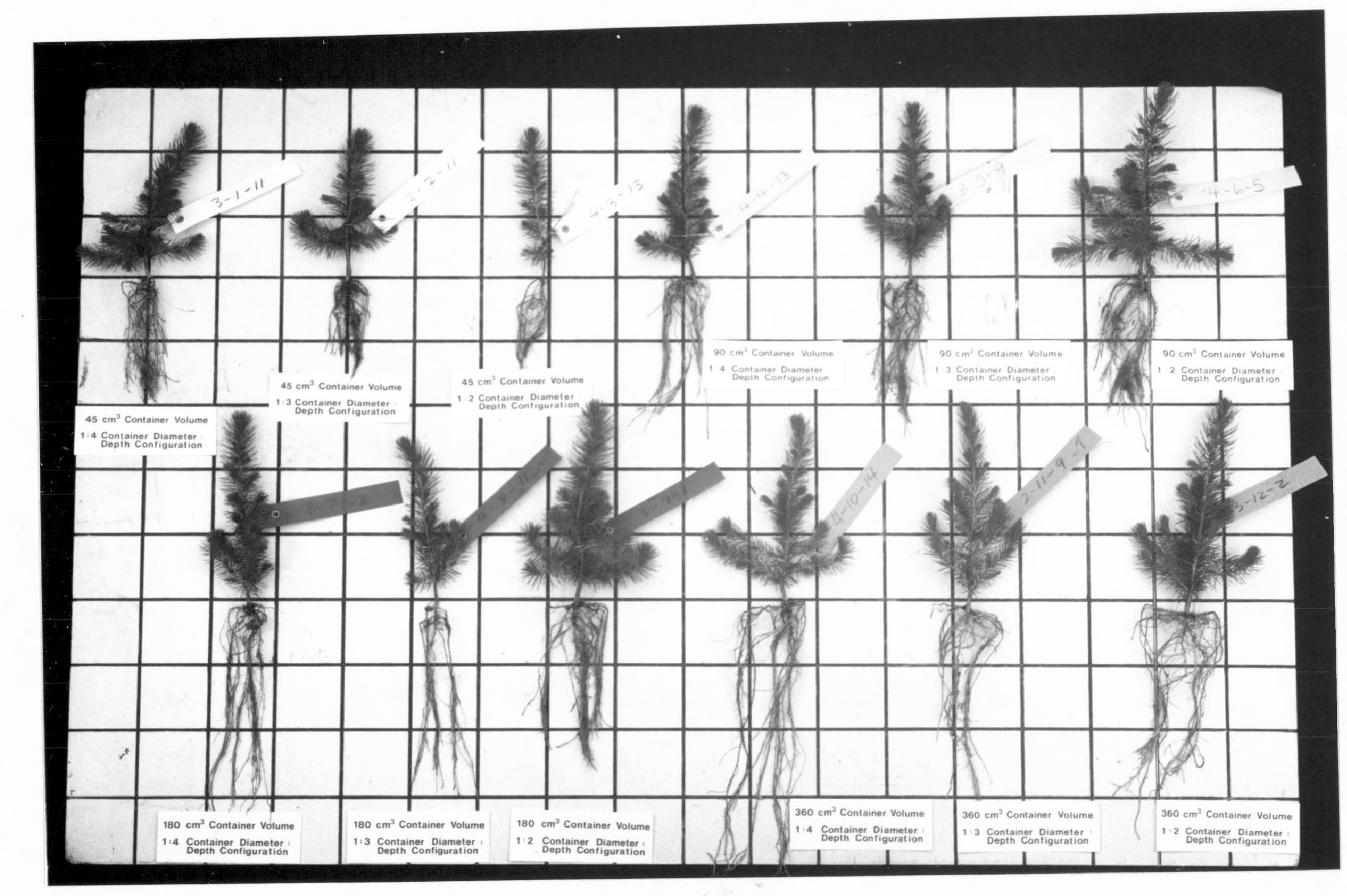

Figure 11. Average black spruce seedlings grown in containers of four volumes and three shapes after 16 weeks in the greenhouse.

Note: the background grid lines are 5 cm apart.

TABLE 12. Summary of ANOVA probabilities for greenhouse data.

Morphological Characteristic	Source of Variation			
	Treatment	Container Volume	Container Dimension	Container Volume x Dimension
Height	**	**	NSD	NSD
Root Collar Diameter	**	**	NSD	NSD
Top Dry Weight	***	***	NSD	NSD
Root Dry Weight	***	***	NSD	NSD
Total Dry Weight	***	***	NSD	NSD
Qix	***	***	NSD	NSD

TABLE 13. Summary of MLR probabilities for greenhouse data.

Morphological Characteristic	Variables in the Equation		
	Container Volume	Container Diameter	Container Depth
Height	***	NSD	***
Root Collar Diameter	*	NSD	*
Top Dry Weight	***	NSD	***
Root Dry Weight	**	NSD	NSD
Total Dry Weight	***	NSD	**
Qix	**	NSD	NSD

Note: *** = $P(F>Fc) < 0.001$

** = $0.01 > P(F>Fc) > 0.001$

* = $0.05 > P(F>Fc) > 0.01$

NSD = No significant difference

TABLE 14. The best fitted regression equations for the greenhouse data.

Equation Number	Equation	R^2 [1]	P(F> Fc) [2]
1	$Ht = \frac{e^{1.82934 + 0.26338 \text{ (Ln Vol.)}}}{e^{0.05191 \text{ (Diam.)} + 0.02281 \text{ (Depth)}}}$	0.15	< 0.0001
	$RCD = \frac{e^{0.55796 + 0.14243 \text{ (Ln Vol.)}}}{e^{0.00017 \text{ (Diam.)} + 0.01395 \text{ (Depth)}}}$	0.15	< 0.0001
	$TDW = \frac{e^{-2.05292 + 0.66221 \text{ (Ln Vol.)}}}{e^{0.14579 \text{ (Diam.)} + 0.05248 \text{ (Depth)}}}$	0.26	< 0.0001
	$RDW = \frac{e^{-3.23908 + 0.49233 \text{ (Ln Vol.)}}}{e^{0.08735 \text{ (Diam.)} + 0.01101 \text{ (Depth)}}}$	0.26	< 0.0001
	$TOTDW = \frac{e^{-1.78129 + 0.62290 \text{ (Ln Vol.)}}}{e^{0.13207 \text{ (Diam.)} + 0.04336 \text{ (Depth)}}}$	0.26	< 0.0001
	$Qix = \frac{e^{3.75545 + 0.49666 \text{ (Ln Vol.)}}}{e^{0.08525 \text{ (Diam.)} + 0.02112 \text{ (Depth)}}}$	0.27	< 0.0001

[1] Note: The coefficient of determination being the per centage of variation in Y attributable to the combined effect of container volume, diameter and depth

[2] Note: The probability of F (variance ratio) being greater than the calculated F is less than 1 chance in 10,000.

All MLR equations had coefficients of deterimation (R^2) between 0.15 and 0.27 and had goodness of fit values (P) less than 0.0001 (Table 14).The MLR analyses showed that all estimated response surfaces produced by the MLR equations were flat, positively sloped planes.

Height

The ANOVA showed that there were signficant differences ($0.01>P>0.001$) between mean heights of the seedlings grown in the 12 container treatments and that the heights were exclusively influenced by container volume (Table 12). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 12). The following differences between treatment means were found (Appendix III):

1) All seedlings grown in 45 cm^3 volume containers were significantly ($0.05>P>0.01$) shorter than those grown in the larger volume containers.

2) No significant differences ($P>0.05$) were found between seedlings grown in 90, 180 and 360 cm^3 volume containers.

3) When the influence of container volume was removed no significant differences ($P>0.05$) were found between seedlings grown at the three container dimensions.

MLR equation (1) in Table 14 best fitted the seedling height data in the greenhouse trial. The Student's t test of the standardized b-coefficients in MLR equation (1) showed the following points (Table 13 and Appendix IV).

1) Seedling height significantly ($P<0.001$) increased with increased container volume.

2) When the influence of container volume was removed, seedling height significantly ($P<0.001$) decreased with increased container depth.

3) Container diameter had no effect on seedling height.

The response surface of the estimated seedling heights produced throughout the range of container treatments is illustrated in Figure 13.

Root Collar Diameter

The ANOVA showed that there were significant differences ($0.01>P>0.001$) between the mean root collar diameters of the seedlings grown in the 12 container treatments and that the root collar diameters were exclusively influenced by container volume. (Table 12). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 14). The following differences between treatment means were found (Appendix III):

1) All seedlings grown in 360 cm^3 volume containers had significantly ($0.05>P>0.01$) larger root collar diameters than those grown in the smaller volume containers.

2) No significant differences ($P>0.05$) were found between the seedlings grown in 45, 90 and 180 cm^3 volume containers.

3) When the influence of container volume was removed no significant differences ($P>0.05$) were found between seedlings grown at the three container dimensions.

MLR equation (2) in Table 14 best fitted the seedling root collar diameter data in the greenhouse. The Student's t tests of the standardized b-coefficients in MLR equation (2) showed the following points (Table 13 and Appendix IV).

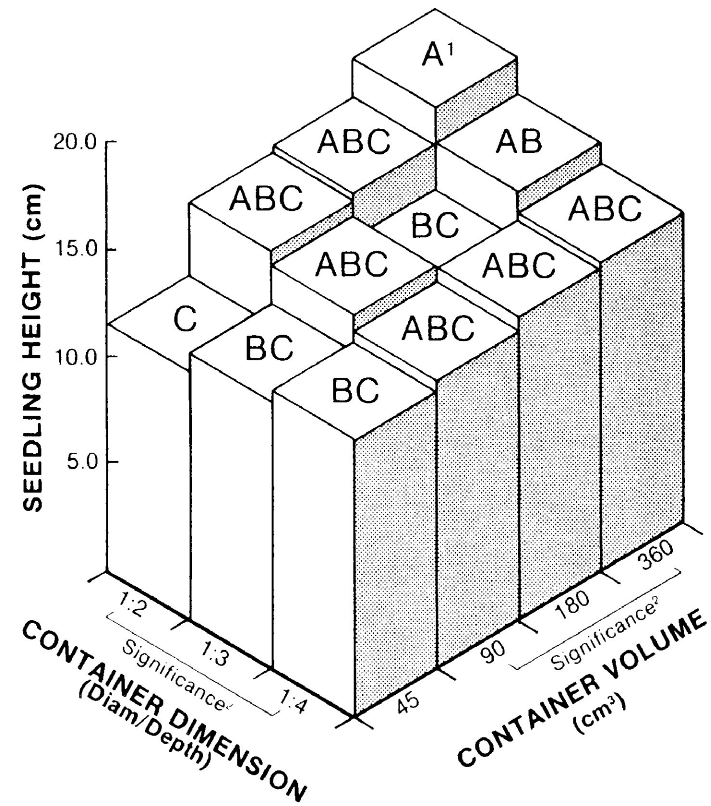

Figure 12: Mean height of black spruce seedlings grown in containers of 4 volumes and 3 dimensions after 16 weeks in the greenhouse.

[1]Note: Treatment means designated with the same letters are not significantly different (P = 0.05)

[2]Note: Main effects joined by a line are not significantly different (P = 0.05)

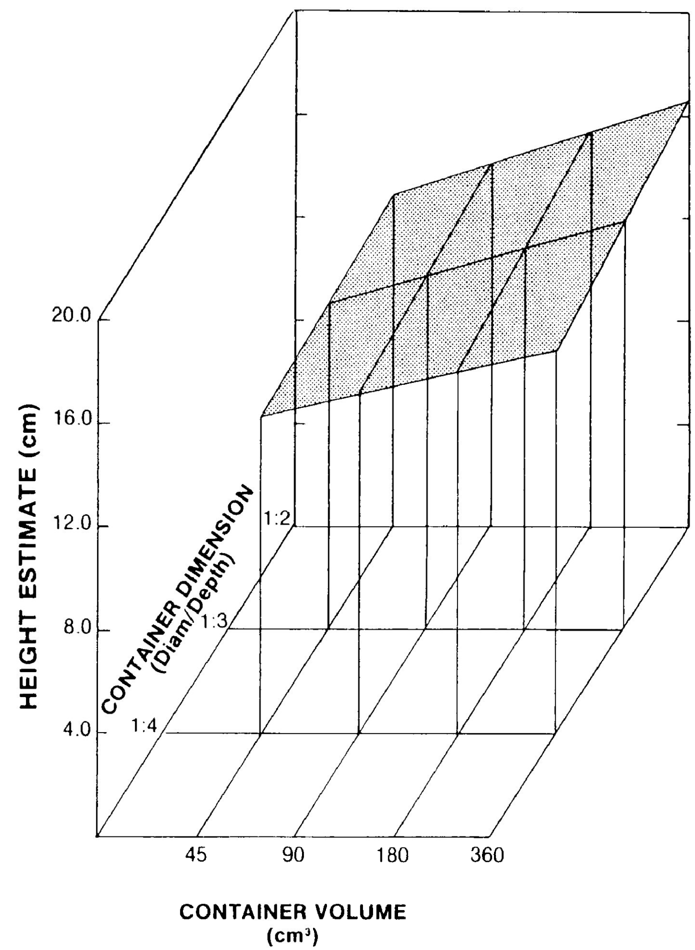

Figure 13: Response surface for the estimated heights of black spruce seedlings throughout the range of container treatments tested after 16 weeks in the greenhouse.

1) Seedling root collar diameter significantly ($0.05>P>0.01$) increased with increased container volume.

2) When the influence of container volume was removed, seedling root collar diameter significantly ($0.05>P>0.01$) decreased with increased container depth.

3) Container diameter had no effect on seedling root collar diameter.

The response surface of estimated seedling root collar diameters produced throughout the range of container treatments is illustrated in Figure 15.

Top Dry Weight

The ANOVA showed that there were significant differences ($P<0.001$) between the mean top dry weights of the seedlings grown in the 12 container treatments and that top dry weights were exclusively influenced by container volume (Table 12). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 16). The following differences between treatment means were found (Appendix III):

1) All seedlings grown in 45 cm^3 volume containers had significantly ($0.01>P>0.001$) less top dry weight than those grown in the larger volume containers.

2) All seedlings grown in 360 cm^3 volume containers had significantly ($0.05>P>0.01$) more top dry weight than those grown in the smaller volume containers.

3) No significant differences ($P>0.05$) were found between the seedlings grown in 90 and 180 cm^3 volume containers.

4) When the influence of container volume was removed, no significant differences

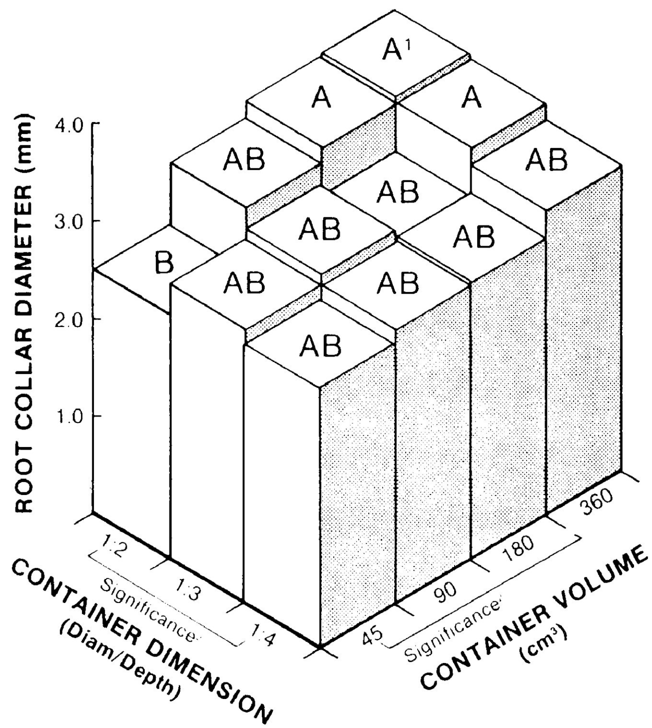

Figure 14: Mean root collar diameter of black spruce seedlings grown in containers of 4 volumes and 3 dimensions after 16 weeks in the greenhouse.

[1]Note: Treatment means designated with the same letters are not significantly different (P = 0.05)

[2]Note: Main effects joined by a line are not significantly different (P = 0.05)

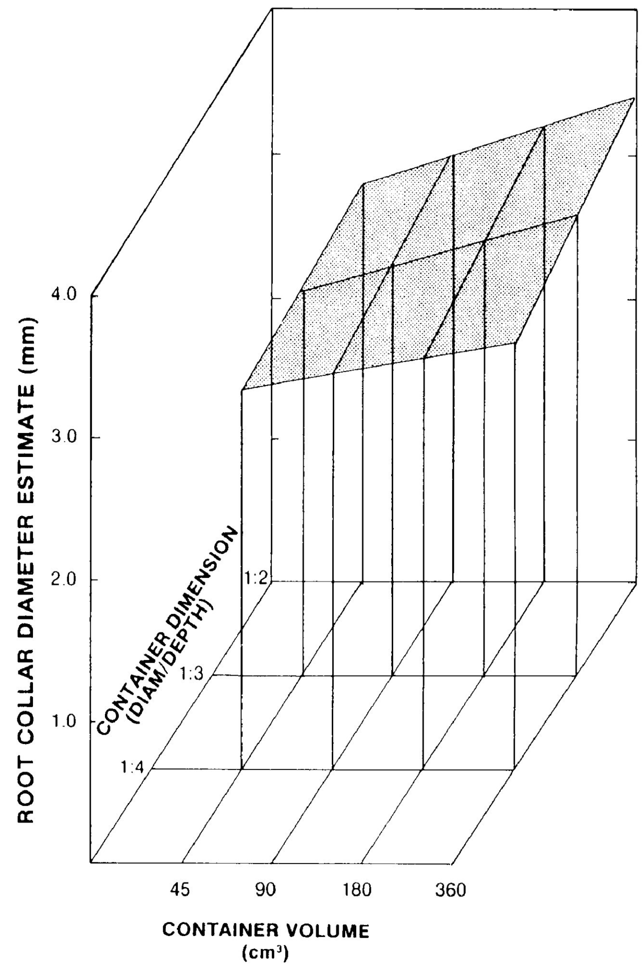

Figure 15: Response surface for the estimated root collar diameters of black spruce seedlings throughout the range of container treatments tested after 16 weeks in the greenhouse.

($P>0.05$) were found between seedlings grown at the three container dimensions.

MLR equation (3) in Table 14 best fitted the seedling top dry weight data in the greenhouse trial. The Student's t test of the standardized b-coefficients in MLR equation (3) showed the following points (Table 13 and Appendix IV).

1) Seedling top dry weight significantly ($P<0.001$) increased with increased container volume.

2) When the influence of container volume was removed, seedling top dry weight significantly ($P<0.001$) decreased with increased container depth.

3) Container diameter had no effect on seedling top dry weight.

The response surface of the estimated seedling top dry weights produced throughout the range of container treatments is illustrated in Figure 17.

Root Dry Weight

The ANOVA showed that there were significant differences ($P<0.001$) between the mean root dry weights of the seedlings grown in the 12 container treatments and that the root dry weights were exclusively influenced by container volume (Table 12). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 18). The following differences between treatment means were found (Appendix III):

1) All seedlings grown in 45 cm^3 volume containers had significantly ($0.01>P>0.001$) less root dry weight than those grown in the larger volume containers.

2) All seedlings grown in 360 cm^3 volume containers had significantly

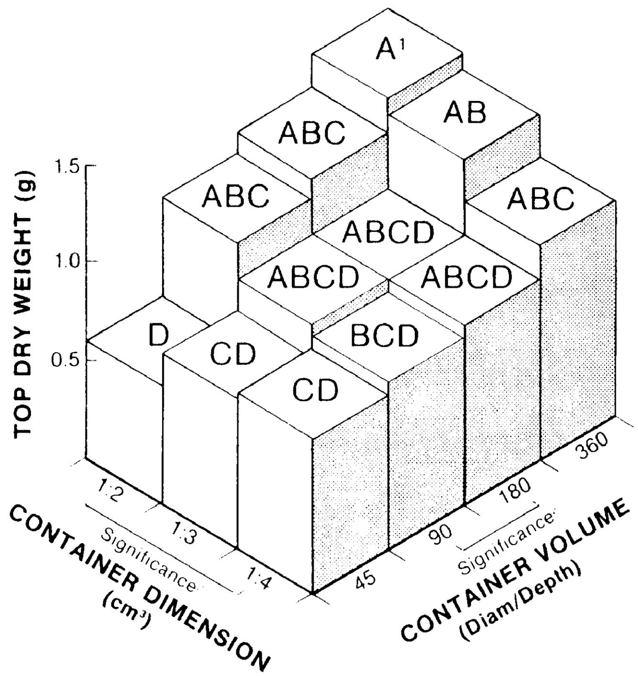

Figure 16: Mean top dry weight of black spruce seedlings grown in containers of 4 volumes and 3 dimensions after 16 weeks in the greenhouse.

[1]Note: Treatment means designated with the same letters are not significantly different (P = 0.05)

[2]Note: Main effects joined by a line are not significantly different (P = 0.05)

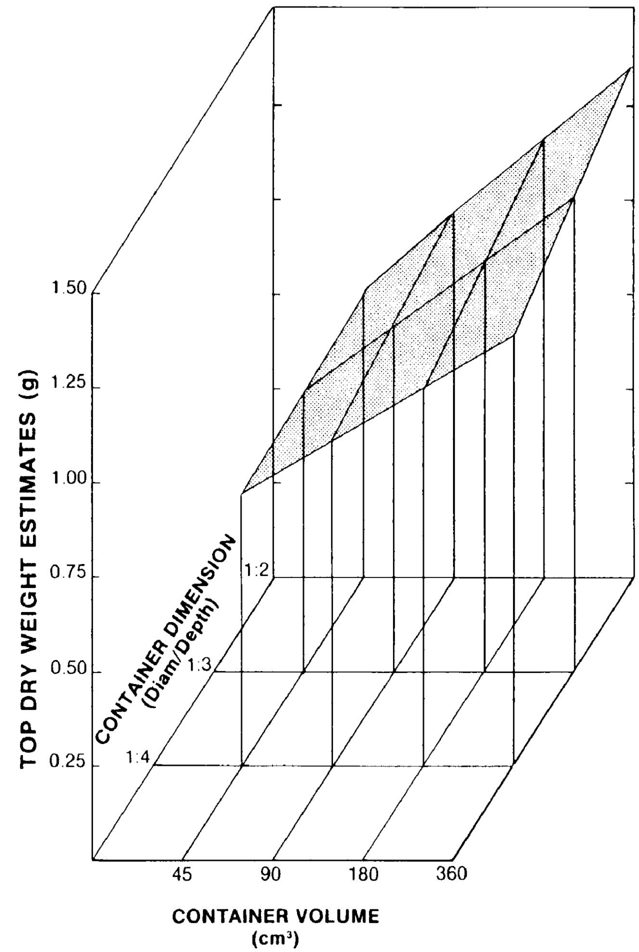

Figure 17: Response surface for the estimated top dry weights of black spruce seedlings throughout the range of container treatments tested after 16 weeks in the greenhouse.

(0.01>P>0.001) more root dry weight than those grown in the smaller volume containers.

3) No significant differences (P>0.05) were found between seedlings grown in 90 and 180 cm^3 volume containers.

4) When the influence of container volume was removed no significant differences (P>0.05) were found between seedlings grown at the three container dimensions.

MLR equation (4) in Table 14 best fitted the seedling root dry weight data in the greenhouse trial. The Student's t test of the standardized b-coefficients in MLR equation (4) showed the following points (Table 13 and Appendix IV).

1) Seedling root dry weight significantly (0.01>P>0.001) increased with increased container volume.

2) When the influence of container volume was removed, seedling root dry weight was not affected by container diameter or depth.

The response surface of the estimated seedling root dry weights produced throughout the range of container treatments is illustrated in Figure 19).

Total Dry Weight

The ANOVA showed that there were significant differences (P<0.001) between the mean total dry weights of the seedlings grown in the 12 container treatments and that the total dry weights were exclusively influenced by container volume (Table 12). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 20). The following differences between treatment means were found

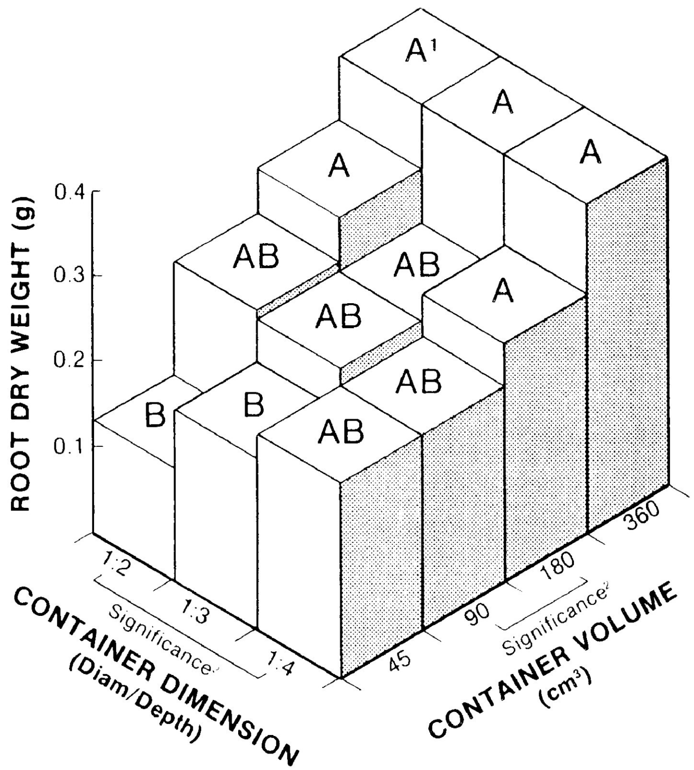

Figure 18: Mean root dry weight of black spruce seedlings grown in containers of 4 volumes and 3 dimensions after 16 weeks in the greenhouse.

[1]Note: Treatment means designated with the same letters are not significantly different (P = 0.05)
[2]Note: Main effects joined by a line are not significantly different (P = 0.05)

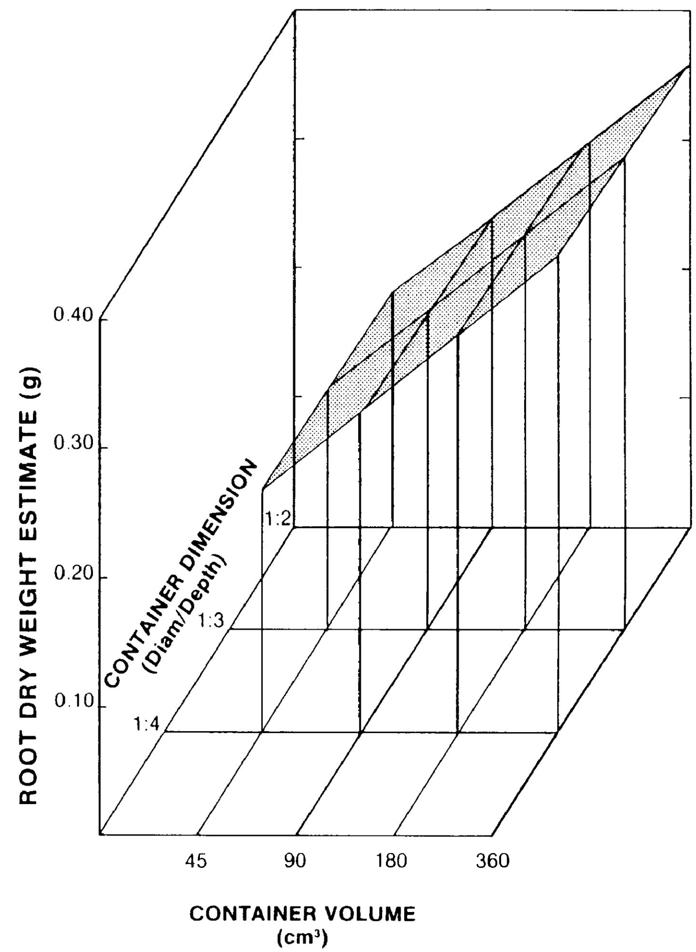

Figure 19: Response surface for the estimated root dry weights of black spruce seedlings throughout the range of container treatments tested after 16 weeks in the greenhouse

(Appendix III):

1) All seedlings grown in 45 cm^3 volume containers had significantly ($0.05>P>0.01$) less dry weight than those grown in the larger volume containers.

2) All seedlings grown in 360 cm^3 volume containers had significantly ($0.01>P>0.001$) more dry weight than those grown in the smaller volume containers.

3) No significant differences ($P>0.05$) were found between seedlings grown in 90 and 180 cm^3 volume containers.

4) When the influence of container volume was removed no significant differences ($P>0.05$) were found between seedlings grown at the three container dimensions.

MLR equation (5) in Table 14 best fitted the seedling total dry weight data in the greenhouse trial. The Student's t test of the standardized b-coefficients in MLR equation (5) showed the following points (Table 13 and Appendix IV).

1) Seedling total dry weight significantly ($P<0.001$) increased with increased container volume.

2) When the influence of container volume was removed, seedling total dry weight significantly ($0.01>P>0.001$) decreased with increased container depth.

3) Container diameter had no effect on seedling total dry weight.

The response surface of the estimated seedling total dry weights produced throughout the range of container treatments is illustrated in Figure 21)

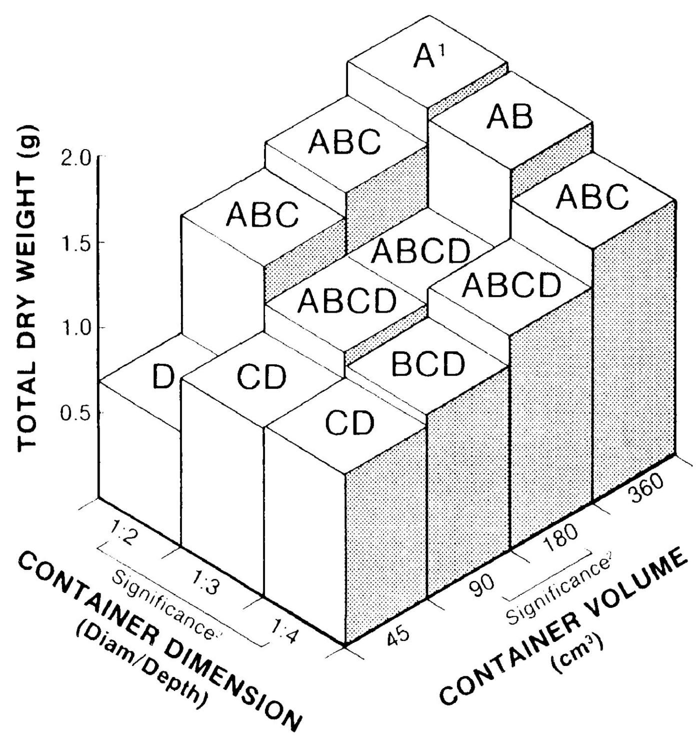

Figure 20: Mean total dry weight of black spruce seedlings grown in containers of 4 volumes and 3 dimensions after 16 weeks in the greenhouse.

[1]Note: Treatment means designated with the same letters are not significantly different (P = 0.05)

[2]Note: Main effects joined by a line are not significantly different (P = 0.05)

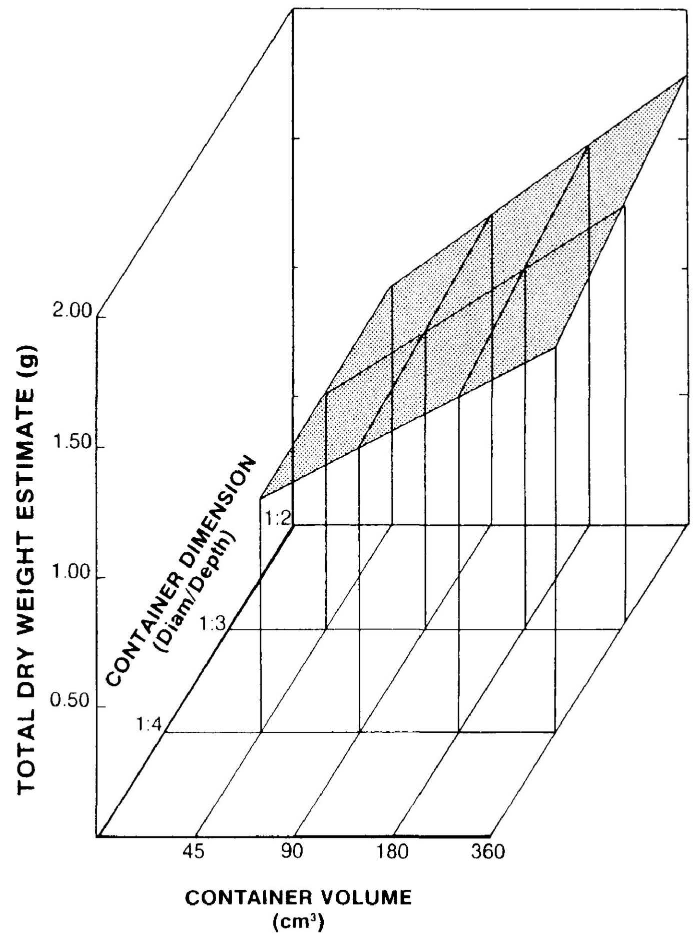

Figure 21: Response surface for the estimated total dry weights of black spruce seedlings throughout the range of container treatments tested after 16 weeks in the greenhouse.

Seedling Quality Index

The ANOVA showed that there were significant differences ($P<0.001$) between the mean seedling quality indices (Qix) of seedlings grown in the 12 container treatments and that the Qix values were exclusively influenced by container volume (Table 12). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 22). The following differences between treatment means were found (Appendix III):

1) All seedlings grown in 45 cm^3 volume containers had significantly ($0.05>P>0.01$) lower Qix values than those grown in the larger volume containers.

2) All seedlings grown in 360 cm^3 volume containers had significantly ($0.01>P>0.001$) higher Qix values than those grown in the smaller volume containers.

3) No significant diffferences ($P>0.05$) were found between seedlings grown in 90 and 180 cm^3 volume containers.

4) When the influence of container volume was removed no significant differences ($P>0.05$) were found between seedlings grown at the three container dimensions.

MLR equation (6) in Table 14 best fitted the Qix data in the greenhouse trial. The Student's t test of the standardized b-coefficients in MLR equation (6) showed the following points (Table 13 and Appendix IV).

1) Seedling Qix significantly ($0.01>P>0.001$) increased with increased container volume.

2) When the influence of container volume was removed, seedling Qix was not

affected by container diameter or depth.

The response surface of the estimated Qix values produced throughout the range of container treatments is illustrated in Figure 23.

FIELD OUTPLANTING PHASE

Analyses of covariance (ANOCA) or analyses of variance (ANOVA), Student-Newman-Keul (SNK) tests and Multiple Linear Regressions (MLR) were carried out for all morphological characteristics and seedling quality indices (Qix) after one growing season in the field. Since the seedlings were removed from the containers before being planted, container volume and shape mentioned throughout the field outplanting phase are the original volumes and shapes of root plugs formed by the containers used in the greenhouse production phase. The average black spruce seedling grown in the 12 container treatments and outplanted for one growing season in the field are shown in Figure 24. The ANOCAs or ANOVAs, SNK tests and MLRs showed the following three general trends in the field data:

1) The ANOCAs or ANOVAs showed that there were highly significant differences ($P<0.001$) between the seedlings grown in the 12 container treatments. Both main effects of container volume and dimension significantly ($P<0.001$) influenced seedling growth (Table 15).

2) The SNK tests also showed that the differences in seedling growth were caused by the influences of container volume and dimension. Exceptions to this trend were that container shape did not influence seedling height and root collar diameters. The SNK tests showed that there was more variation in dry weight

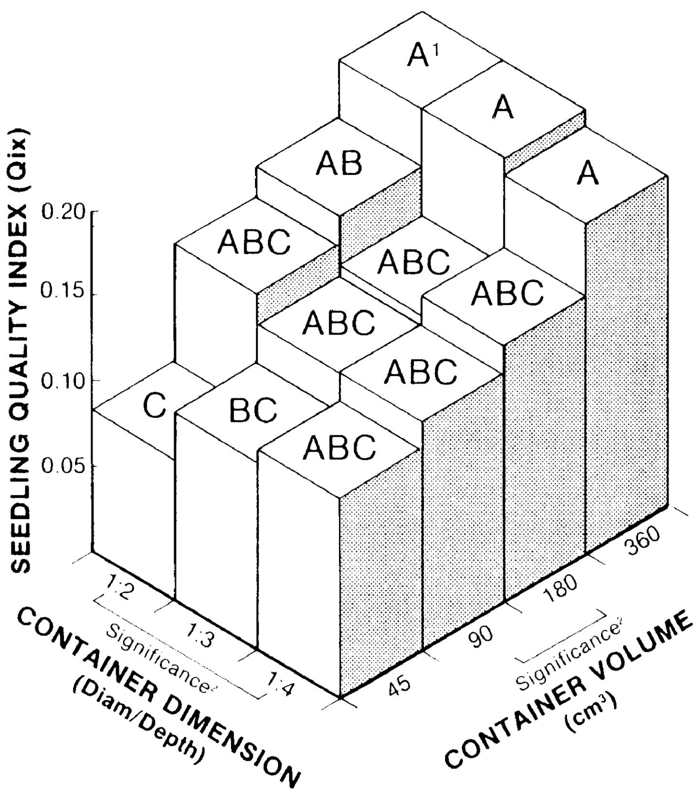

Figure 22: Mean seedling quality indices of black spruce grown in containers of 4 volumes and 3 dimensions after 16 weeks in the greenhouse.

[1]Note: Treatment means designated with the same letters are not significantly different ($P = 0.05$)
[2]Note: Main effects joined by a line are not significantly different ($P = 0.05$)

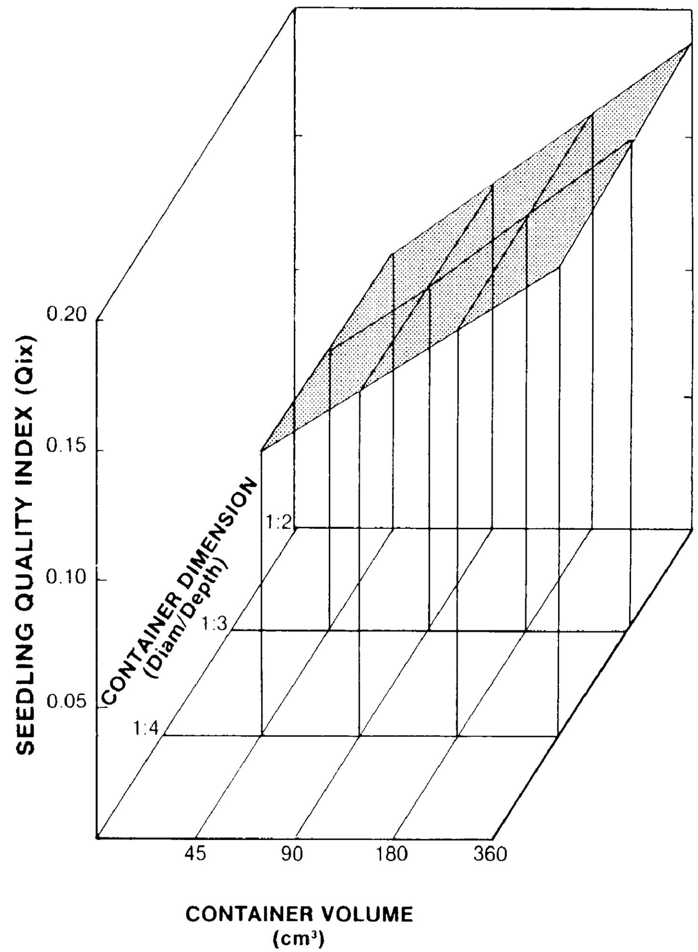

Figure 23: Response surface for the estimated seedling quality indices of black spruce seedlings throughout the range of container treatments tested after 16 weeks in the greenhouse.

Figure 24. Average black spruce seedlings originally grown in containers of four volumes and three shapes after one growing season in the field.

Note: the background grid lines are 5 cm apart.

than in height and root collar diameters (Appendix V).

3) The MLRs showed that the differences in seedling growth in the field were caused by the influences of container volume, diameter and depth (Table 16). The MLR equations for the morphological characteristics and Qix values are illustrated in Table 17.

All MLR equations had coefficients of determination (R^2) between 0.35 and 0.50 and had goodness of fit values (P) less than 0.0001 (Table 17). The MLR analyses showed that all estimated response surfaces produced by the MLR equations were curved, positively sloped planes.

Height

The ANOCA showed that there were significant differences ($P<0.001$) between the mean heights of the seedlings grown in the 12 container treatments and that the heights were influenced by both container volume and shape (Table 15). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 25). The following differences between treatment means were found (Appendix V):

1) All seedlings grown in 45 cm^3 volume containers were significantly ($P>0.001$) shorter than those grown in the larger volume containers.

2) No significant differences ($P>0.05$) were found between seedlings grown in 90, 180 and 360 cm^3 volume containers.

3) When the influence of container volume was removed no significant differences ($P>0.05$) were found between seedlings grown at the three container shapes.

TABLE 15. Summary of ANOVA probabilities for field data

Morphological Characteristic	Source of Variation			
	Treatment	Container Volume	Container Dimension	Container Volume x Dimension
Height	***	***	***	NSD
Root Collar Diameter	***	***	*	NSD
Top Dry Weight	***	***	***	*
Root Dry Weight	***	***	***	NSD
Total Dry Weight	***	***	***	*
Qix	***	***	***	NSD

Note: *** = P(F>Fc) < 0.001
** = 0.01 > P(F>Fc) > 0.001
* = 0.05 > P(F>Fc) > 0.01
NSD = No significant difference

TABLE 16. Summary of MLR probabilities for field data

Morphological Characteristic	Variables in the Equation		
	Container Volume	Container Diameter	Container Depth
Height	***	***	***
Root Collar Diameter	**	NSD	*
Top Dry Weight	***	***	***
Root Dry Weight	***	*	***
Total Dry Weight	***	***	***
Qix	***	NSD	***

Note: *** = P(F>Fc) < 0.001
** = 0.01 >P(F>Fc)> 0.01
* = 0.05 >P(F>Fc)> 0.01
NSD = No significant difference

TABLE 17. The best fitted regression equations for the field data.

Equation Number	Equation	R^2 [1]	P(F > Fc) [2]
1	$Ht = \frac{e^{1.13587 + 0.77666 \text{ (Ln Vol.)}}}{e^{0.24823 \text{ (Diam.)} + 0.06620 \text{ (Depth)}}}$	0.42	< 0.0001
	$RCD = \frac{e^{0.44750 + 0.27641 \text{ (Ln Vol.)}}}{e^{0.02968 \text{ (Diam.)} + 0.01960 \text{ (Depth)}}}$	0.36	< 0.0001
	$TDW = \frac{e^{-2.64381 + 1.30855 \text{ (Ln Vol.)}}}{e^{0.35485 \text{ (Diam.)} + 0.10407 \text{ (Depth)}}}$	0.50	< 0.0001
	$RDW = \frac{e^{-2.78823 + 1.15889 \text{ (Ln Vol.)}}}{e^{0.030883 \text{ (Diam.)} + 0.09495 \text{ (Depth)}}}$	0.35	< 0.0001
	$TOTDW = \frac{e^{-1.94163 + 1.23441 \text{ (Ln Vol.)}}}{e^{0.32923 \text{ (Diam.)} + 0.09877 \text{ (Depth)}}}$	0.48	< 0.0001
	$Qix = \frac{e^{-3.17366 + 0.88396 \text{ (Ln Vol.)}}}{e^{0.20482 \text{ (Diam.)} + 0.06723 \text{ (Depth)}}}$	0.36	< 0.0001

[1] Note: The coefficient of determination being the per centage of variation in Y attributable to the combined effect of container volume, diameter and depth

[2] Note: The probability of F (variance ratio) being greater than the calculated F is less than 1 chance in 10,000.

MLR equation (1) in Table 17 best fitted the seedling height data in the field trial. The Student's t test of the standardized b-coefficients in MLR equation (1) showed the following points (Table 16, Appendix VI and VII).

1) Seedling height significantly ($P<0.001$) increased with increased container volume.

2) When the influence of container volume was removed, seedling height :

   a) significantly ($P<0.001$) increased with increased container diameter,

   b) significantly ($P<0.001$) decreased with increased container depth.

The response surface of the estimated seedling heights produced throughout the range of container treatments is illustrated in Figure 26.

Root Collar Diameter

The ANOVAs showed that there were significant differences ($P<0.001$) between the mean root collar diameters of the seedlings grown in the 12 container treatments and that the root collar diameters were influenced by both container volume and shape (Table 15). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 27). The following differences between treatment means were found (Appendix V):

1) All seedlings grown in 45 cm^3 volume containers had significantly ($P>0.001$) smaller root collar diameters than those grown in the larger volume containers.

2) All seedlings grown in 360 cm^3 volume containers had signficantly ($P>0.001$) larger root collar diameters than those grown in the smaller volume containers.

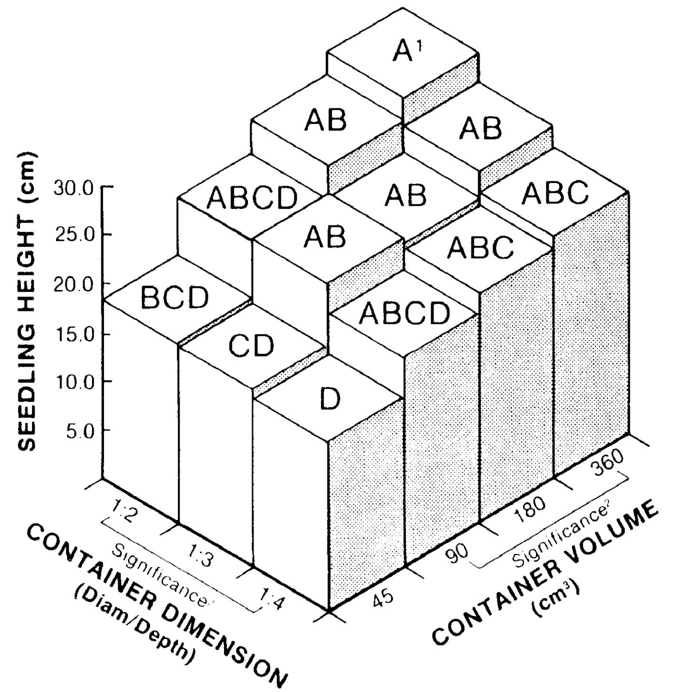

Figure 25: Mean height of black spruce seedlings grown in containers of 4 volumes and 3 dimensions after one growing season in the field.

[1]Note: Treatment means designated with the same letters are not significantly different (P = 0.05)

[2]Note: Main effects joined by a line are not significantly different (P = 0.05)

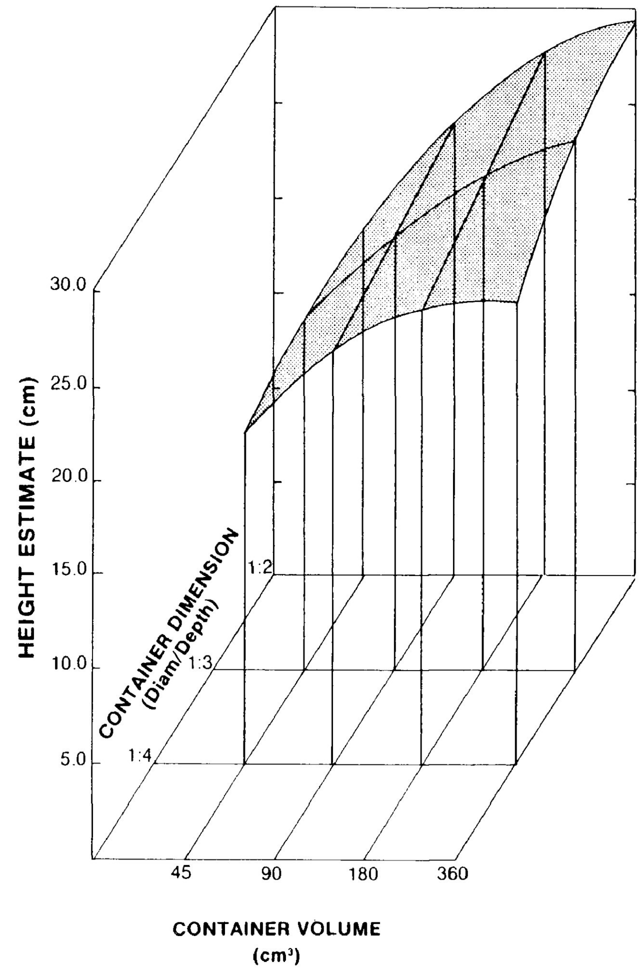

Figure 26: Response surface for the estimated heights of black spruce seedlings throughout the range of container treatments tested after one growing season in the field.

3) No significant differences ($P>0.05$) were found between seedlings grown in 90 and 180 cm^3 volume containers.

4) When the influence of container volume was removed no significant differences ($P>0.05$) were found between seedlings grown at the three container shapes.

MLR equation (2) in Table 17 best fitted the sedling root collar diameter data in the field trial. The Student's t test of the standardized b-coefficients in MLR equation (2) showed the following points (Table 16, Appendix VI and VII).

1) Seedling root collar diameter significantly ($0.01>P>0.001$) increased with increased container volume.

2) When the influence of container volume was removed, seedling root collar diameter:

   a) did not significantly ($P<0.05$) increase with increased container diameter,

   b) significantly ($0.05>P>0.01$) decreased with increased container depth.

The response surface of the estimated seedling root collar diameters produced throughout the range of container treatments is illustrated in Figure 28.

Top Dry Weight

The ANOVA showed that there were significant differences ($P<0.001$) between the mean top dry weights of the seedlings grown in the 12 container treatments and that the top dry weights were influenced by container volume, shape and their interactions (Table 15). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 29). The following differences between treatment means

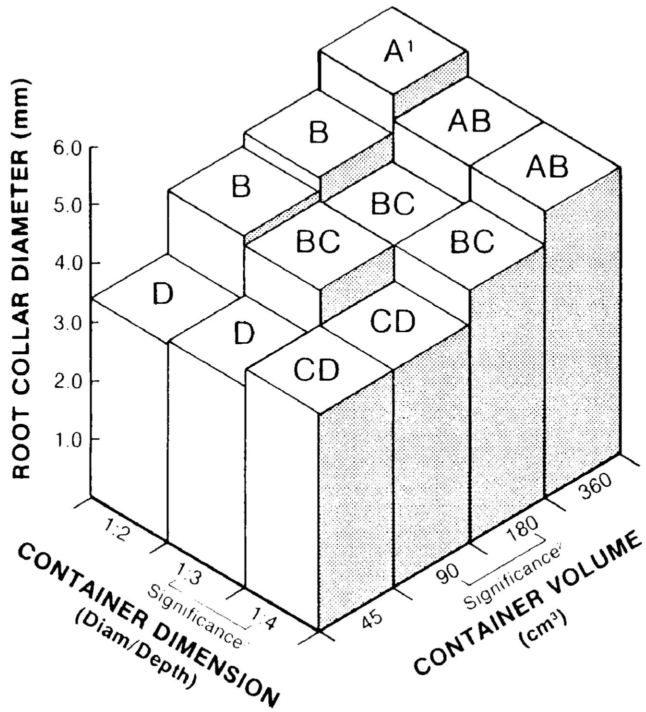

Figure 27: Mean root collar diameter of black spruce seedlings grown in containers of 4 volumes and 3 dimensions after one growing season in the field.

[1]Note: Treatment means designated with the same letters are not significantly different (P = 0.05)

[2]Note: Main effects joined by a line are not significantly different (P = 0.05)

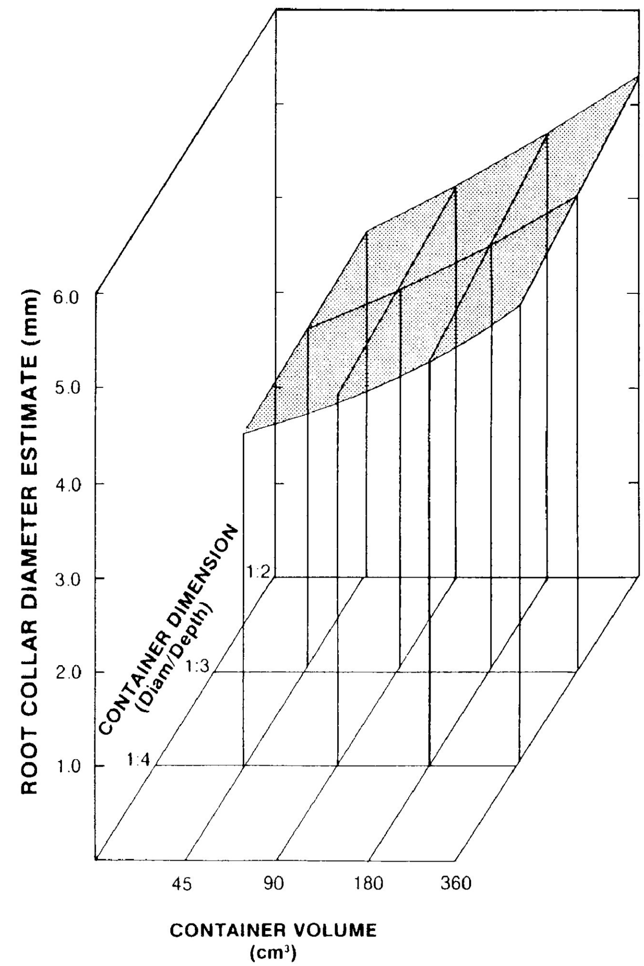

Figure 28: Response surface for the estimated root collar diameters of black spruce seedlings throughout the range of container treatments tested after one growing season in the field

were found (Appendix V):

1) All seedlings grown in the four container volumes were significantly different ($P>0.001$) and significantly increased in top dry weight with increases in container volume.

2) When the influene of container volume was removed seedlings grown at the 1:2 container shape were significantly heavier ($0.01>P>0.001$) than the seedlings grown at the 1:3 and 1:4 container shapes.

3) No significant differences ($P>0.05$) were found between seedlings grown at the 1:3 and 1:4 container shapes.

MLR equation (3) in Table 17 best fitted the seedling top dry weight data in the field trial. The Student's t test of the standardized b-coefficients in MLR equation (3) showed the following points (Table 16, Appendix VI and VII).

1) Seedling top dry weight significantly ($P<0.001$) increased with increased container volume.

2) When the influence of container volume was removed, seedling top dry weight:

   a) significantly ($P<0.001$) increased with increased container diameter,

   b) significantly ($P<0.001$) decreased with increased container depth.

The response surface of the estimated seedling top dry weights produced throughout the range of container treatments is illustrated in Figure 30.

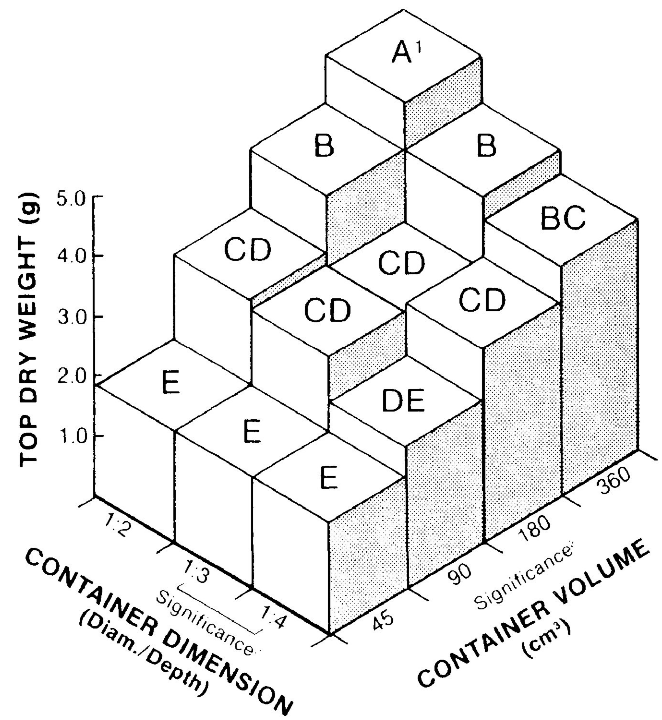

Figure 29: Mean top dry weight of black spruce seedlings grown in containers of 4 volumes and 3 dimensions after one growing season in the field.

[1]Note: Treatment means designated with the same letters are not significantly different (P = 0.05)

[2]Note: Main effects joined by a line are not significantly different (P = 0.05)

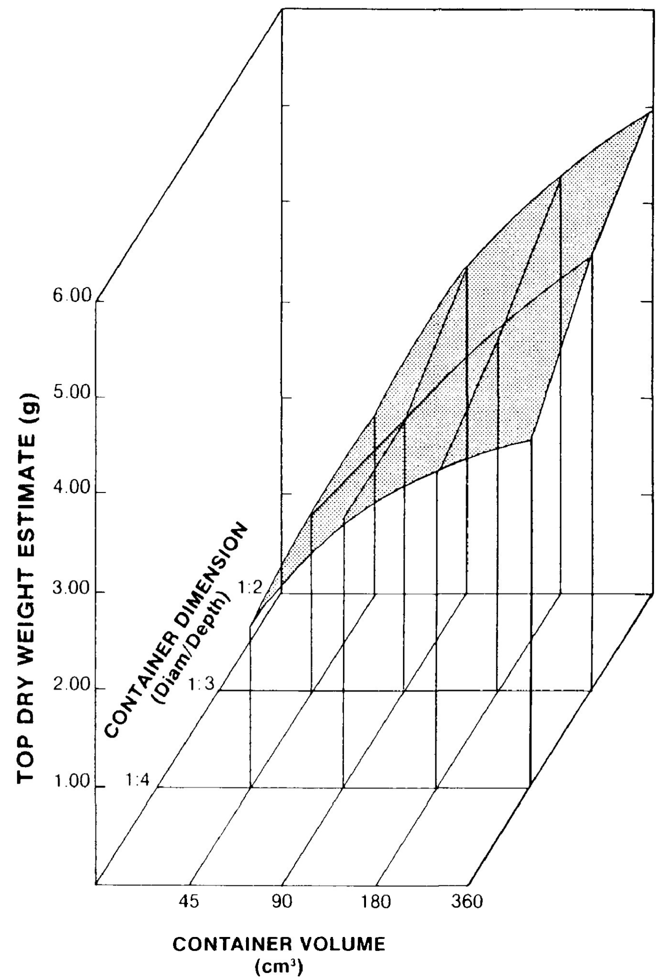

Figure 30: Response surface for the estimated top dry weights of black spruce seedlings throughout the range of container treatments tested after one growing season in the field.

Root Dry Weight

The ANOVA showed that there were significant differences ($P<0.001$) between the mean root dry weights of the seedlings grown in the 12 container treatments and that the root dry weights were influenced by both container volume and shape (Table 15). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 31). The following differences between treatment means were found (Appendix V):

1) All seedlings grown in the four container volumes were significantly different ($0.05>P>0.01$) and significantly increased in root dry weight with increases in container volume.

2) When the influence of container volume was removed seedlings grown at the 1:2 container shape were significantly heavier ($0.01>P>0.001$) than those grown at the 1:3 and 1:4 container shapes.

3) No significant differences ($P>0.05$) were found between seedlings grown at the 1:3 and 1:4 container shapes.

MLR equation (4) in Table 17 best fitted the seedling root dry weight data in the field trial. The Student's t test of the standardized b-coefficients in MLR equation (4) showed the following points (Table 16, Appendix VI and VII).

1) Seedling root dry weight significantly ($P<0.001$) increased with increased container volume.

2) When the influence of container volume was removed, seedling root dry weight:

   a) significantly ($0.05>P>0.01$) increased with increased container diameter,

b) significantly ($P<0.001$) decreased with increased container depth.

The response surface of the estimated seedling root dry weights produced throughout the range of container treatments is illustrated in Figure 32.

Total Dry Weight

The ANOVA showed that there were significant differences ($P<0.001$) between the mean total dry weights of the seedlings grown in the 12 container treatments and that the total dry weights were influenced by container volume, shape and their interactions (Table 15). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 33). The following differences between treatment means were found (Appendix V):

1) All seedlings grown in the four container volumes were significantly different ($P<0.001$) and significantly increased in dry weight with increases in container volume.

2) When the influence of container volume was removed seedlings grown at the 1:2 container shape were significantly heavier ($0.01>P>0.001$) than those grown at the 1:3 and 1:4 container shapes.

3) No significant differences ($P>0.05$) were found between seedlings grown at the 1:3 and 1:4 container shapes.

MLR equation (5) in Table 17 best fitted the seedling total dry weight data in the field trial. The Student's t test of the standardized b-coefficients in MLR equation (5) showed the following points (Table 16, Appendix VI and VII).

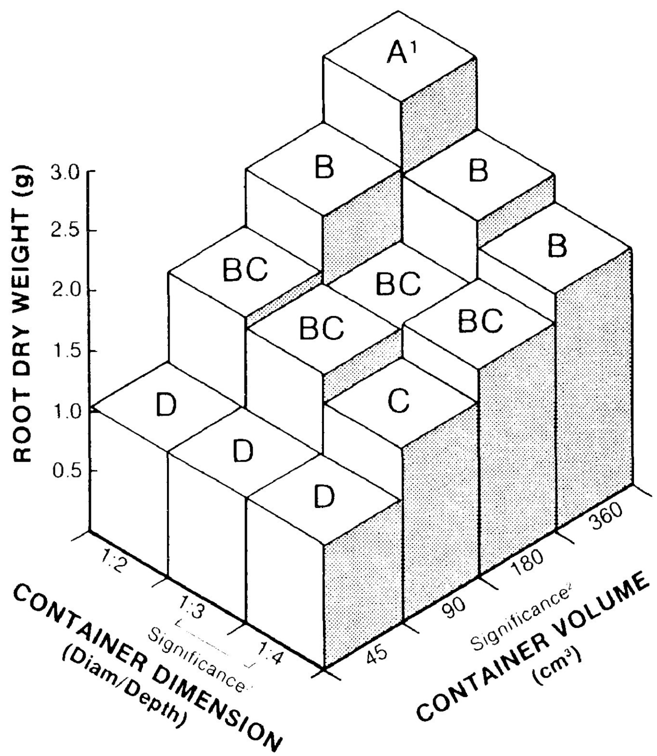

Figure 31: Mean root dry weight of black spruce seedlings grown in containers of 4 volumes and 3 dimensions after one growing season in the field.

[1]Note: Treatment means designated with the same letters are not significantly different (P = 0.05)

[2]Note: Main effects joined by a line are not significantly different (P = 0.05)

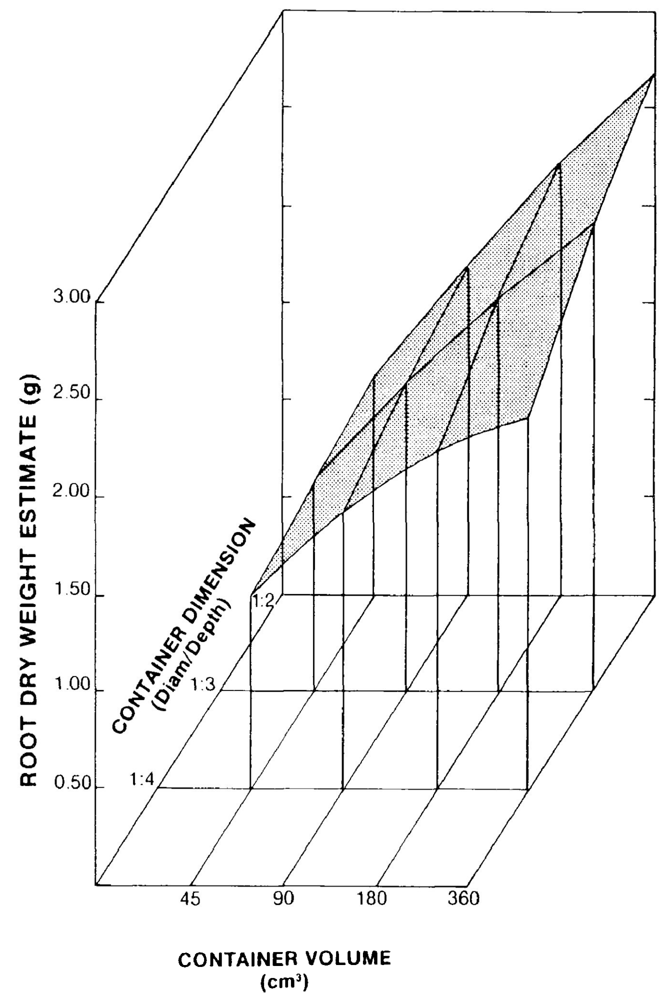

Figure 32: Response surface for the estimated root dry weights of black spruce seedlings throughout the range of container treatments tested after one growing season in the field.

1) Seedling total dry weight significantly ($P<0.001$) increased with increased container volume.

2) When the influence of container volume was removed, seedling total dry weight:

    a) significantly ($P<0.001$) increased with increased container diameter,

    b) significantly ($P<0.001$) decreased with increased container depth.

The response surface of the estimated seedling total dry weights produced throughout the range of container treatments is illustrated in Figure 34.

Seedling Quality Index

The ANOVA showed that there were significant differences ($P<0.001$) between the mean seedling quality indices (Qix) of seedlings grown in the 12 container treatments and that the Qix values were influenced by both container volume and shape (Table 15). The treatment means and SNK test results are presented on a three-dimensional bar graph (Figure 35). The following differences between treatment means were found (Appendix V):

1) All seedlings grown in the four container volumes were significantly different ($0.05>P>0.01$) and the Qix values increased significantly with increases in container volume.

2) When the influence of container volume was removed, seedlings grown at the 1:2 container shape had significantly ($0.05>P>0.01$) higher Qix values than those grown at the 1:3 and 1:4 container shapes.

3) No significant differences ($P>0.05$) were found between seedlings grown at the

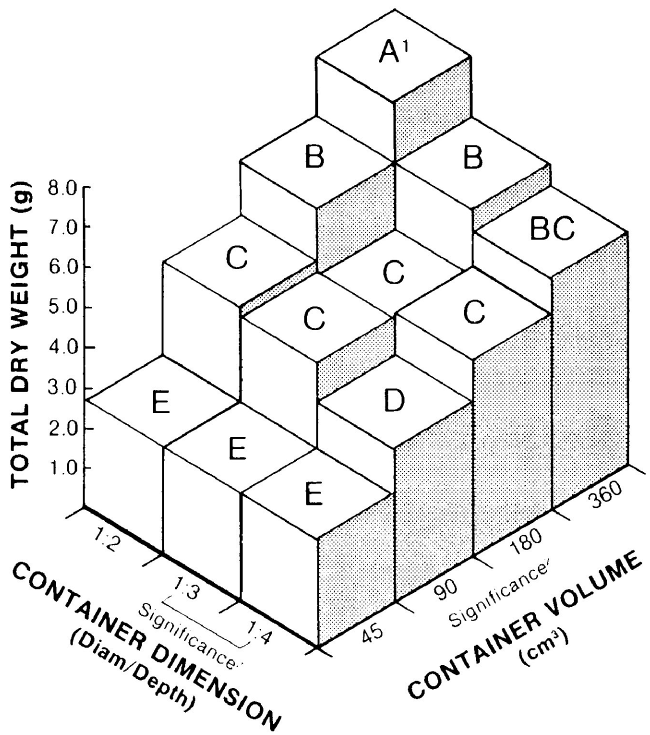

Figure 33: Mean total dry weight of black spruce seedlings grown in containers of 4 volumes and 3 dimensions after one growing season in the field.

[1]Note: Treatment means designated with the same letters are not significantly different (P = 0.05)

[2]Note: Main effects joined by a line are not significantly different (P = 0.05)

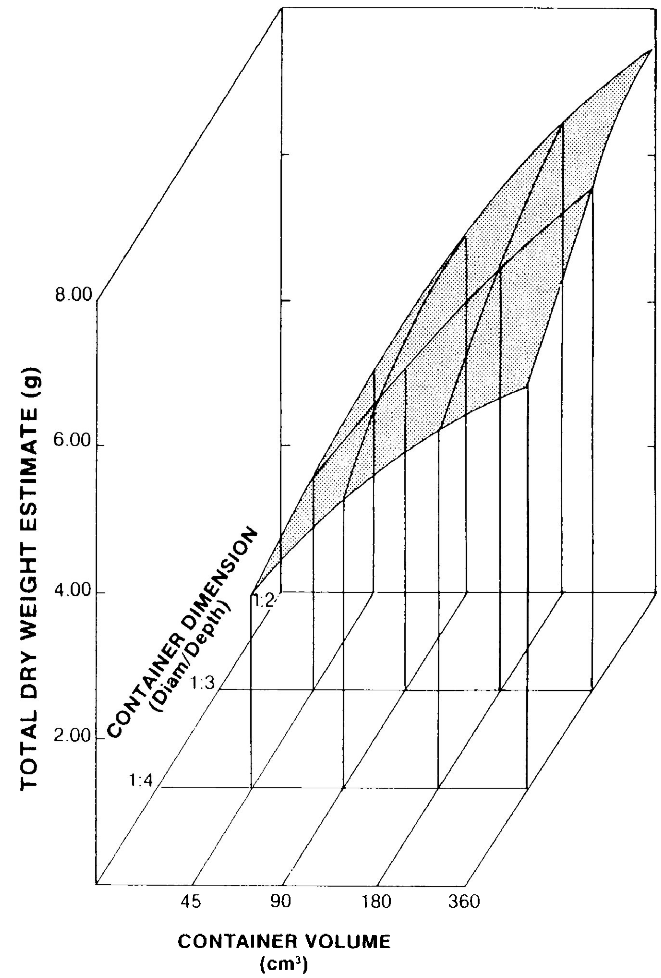

Figure 34: Response surface of the estimated total dry weights of black spruce seedlings throughout the range of container treatments tested after one growing season in the field.

1:3 and 1:4 container shapes.

MLR equation (6) in Table 17 best fitted the seedling quality index data in the field trial. The Student's t test of the standardized b-coefficients in MLR equation (6) showed the following points (Table 16, Appendix VI and VII).

1) Seedling Qix significantly ($P<0.001$) increased with increased container volume.

2) When the influence of container volume was removed, seedling Qix significantly ($P<0.001$) decreased with increased container depth.

3) Container diameter had no effect on Qix.

The response surface of the estimated Qix values produced throughout the range of container treatments is illustrated in Figure 36.

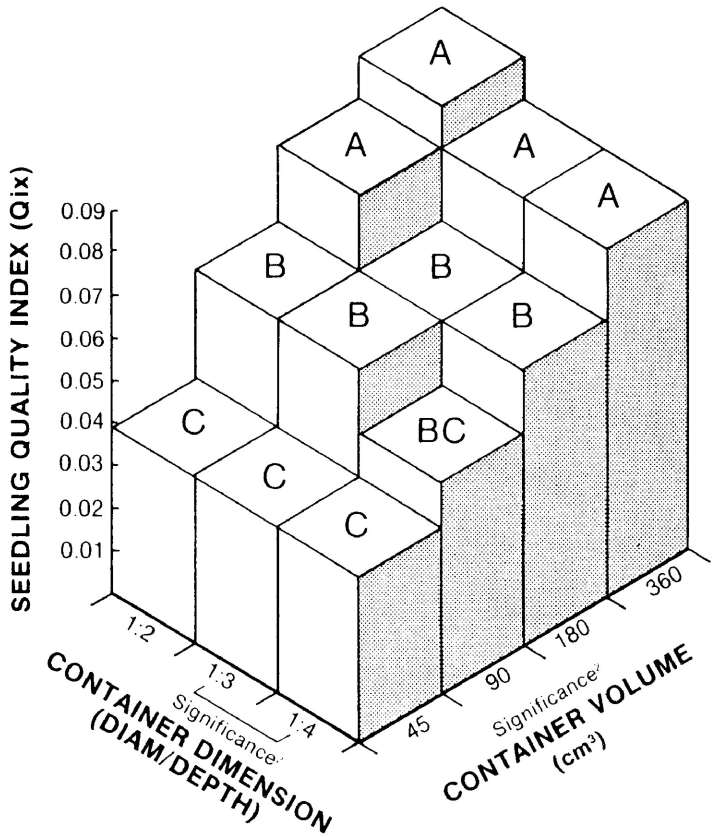

Figure 35: Mean seedling quality indices for black spruce grown in containers of 4 volumes and 3 dimensions after one growing season in the field.

[1]Note: Treatment means designated with the same letters are not significantly different (P = 0.05)

[2]Note: Main effects joined by a line are not significantly different (P = 0.05)

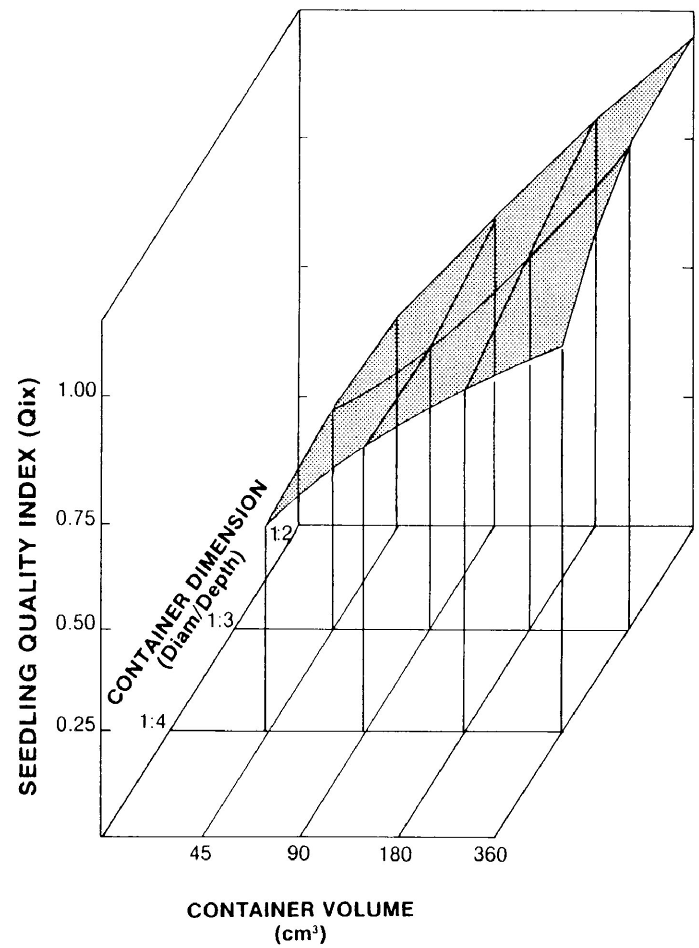

Figure 36: Response surface of the estimated seedling quality indices of black spruce seedlings throughout the range of container treatments tested after one growing season in the field.

DISCUSSION

GREENHOUSE PRODUCTION PHASE

Effects of Container Volume

At the end of the greenhouse production phase the ANOVAs showed that the height, root collar diameter, top, root and total dry weight and the quality index (Qix) of black spruce container stock were significantly influenced by container volume (Table 12). The Student's t tests of the standardized b-coefficients in the MLR equations (Table 14) also showed that these characteristics and Qix values of black spruce container stock were significantly influenced by container volume (Table 13).

All morphological characteristics and Qix values generally increased significantly with increasing container volume (Figure 11 and Appendix III). These results concur with numerous reports of other tree species and most closely with those of Scarratt (1981) who also found that black spruce increased in size with increasing container volume during the greenhouse production phase.

The ANOVA and MLR results in this study suggest the following points.

1) Black spruce should not be grown in containers of less than 90 cm^3.

2) Black spruce should be grown in containers that range in volume from 90 and 360 cm^3. The decision to use a certain size of container in this volume range will depend on a) the stock size and quality desired, b) production schedules and c) production budgets.

Lateral root deformation and/or soil moisture may be two possible reasons why container volume has affected the growth of black spruce in the greenhouse.

Lateral Root Deformation

Containers provide a finite growing space for root development during the greenhouse production phase. This physical restriction on root development (especially lateral root development) of black spruce may limit seedling growth.

In almost all container types, lateral root growth is impeded by the container wall. Once a root makes contact with the container wall, it abruptly changes direction and grows vertically downward along it. Lateral root deformation of this type is called the 'pot-binding phenomenon' by Furuta (1976) and has been well documented by Biran and Eliassaf (1980a), Bohm (1979), de Champs (1978), Ferdinand (1972) and Tinus (1978).

The sharp bends or kinks formed in the lateral roots, at the point of contact with the container wall, may cause physical weakness in the roots and restrict the uptake of water and nutrients and the translocation of food (Harris, 1967). It seems reasonable to hypothesize that the radial distance the deformation is from the seedling stem may influence the efficiency of the root system. Because container radius is a function of container volume the redirection of roots growing laterally occurs early in small volume containers. Deformed root systems may be less efficient because: 1) more of the root system is restricted below the points of deformation, and 2) fewer sinker roots would be allowed to develop (Figure 37). This hypothesis concurs with the results of many studies which showed that nutrient uptake increased with an increase in container volume (Baker and Woodruff, 1962; Bohm, 1979; Cornforth, 1968; Hay and Woods, 1978; Larsen

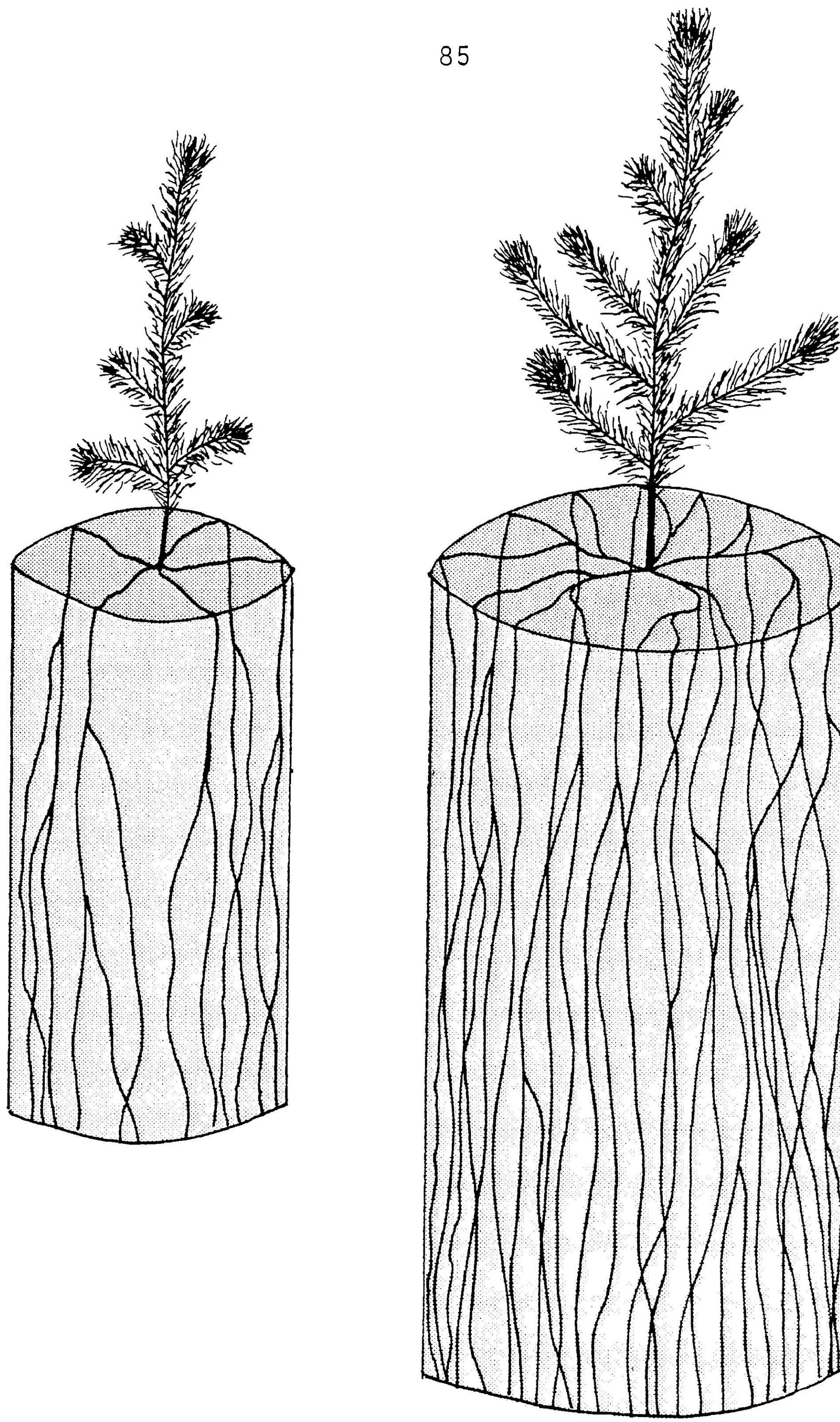

Figure 37. Root system configurations of black spruce in small and large volume containers.

and Sutton, 1963; Russell and Newbould, 1968; Stevenson, 1970). As black spruce seedlings principally develop lateral roots with small sinker roots (Schultz, 1969), their growth may be severely hampered by the restriction of lateral roots when they are grown in small volume and diameter containers.

Soil Moisture

A container of a given volume can physically only hold a finite quantity of soil moisture at one time in the greenhouse production phase (Day and Skoupy, 1971). If the volume of the container is too small, soil moisture may become limited when transpiration rates are high. This may hamper photosynthetic rate and seedling growth if drought conditions occur too frequently or for extended periods (Sutton, 1969; Zavitkovski and Ferrell, 1968). This hypothesis concurs with the results of this study and of Kratky et al (1982) and Van Eerden (1974).

Effects of Container Shape

At the end of the greenhouse production phase the ANOVAs showed that the height, root collar diameter, top, root and total dry weight and quality index (Qix) of black spruce container stock were not significantly influenced by container shape (Table 12). These results concur with the results of Carlson and Endean (1976), Endean and Carlson (1975) and Scarratt (1972a) who found no significant differences in the growth of seedlings in different container shapes. Although there were no significant differences, all the morphological characteristics and Qix values of black spruce generally increased as container shape changed from a deep, narrow (1:4) container to a shallow, wide (1:2) container. An exception to this general trend was found with the three shapes of 45 cm^3 containers. Black spruce grew best in the tall, narrow (1:4) containers and growth decreased with change in container shape from 1:3 to 1:2 (Figure 11, Appendix III and IV).

The Student's t tests of the standardized b-coefficients in the MLR equations (Table 14) showed that the height, root collar diameter, top and total dry weights of black spruce seedlings were significantly influenced by container depth but were not influenced by container diameter (Table 13). At each container volume in the 90 to 360 cm^3 range, all morphological characteristics and Qix values decreased with increasing container depth. The reverse trend occurred in the 45 cm^3 containers (Appendix IV).

The differences in the significance of container shape in the ANOVAs and MLRs can be explained as follows. In the MLRs container diameter and depth were treated as separate factors and container depth significantly influenced seedling growth. However, in the ANOVAs container diameter and depth were treated as a ratio. No significant differences were found because the ratio masked the influence of container depth.

The ANOVA and MLR results in this study suggest the following points.

1) Black spruce should be grown in a container shape that approaches its natural rooting pattern. A shallow, wide container may minimize the influences of lateral root deformation. Deep, narrow containers should be avoided.

2) Black spruce should not be grown in containers less than 90 cm^3 with a 1:2 diameter/depth shape because the container depth may be too short for proper root and subsequent shoot development. This concurs with Boudoux (1972) who

suggested that the minimum container depth for growing black spruce be at least 7 cm.

3) The ANOVAs might have shown significant differences if the greenhouse production phase had been extended beyond 16 weeks or if the seedlings were held for an extended period before being outplanted.

FIELD OUTPLANTING PHASE

Effects of Container Volume

After one growing season in the field the ANOVAs and ANOCAs showed that the height, root collar diameter, top, root and total dry weight and the quality index (Qix) of black spruce container stock were significantly influenced by the original container volume (Table 15). The Student's t tests of the standardized b-coefficients in the MLR equations (Table 17) also showed that these morphological characteristics and Qix values of black spruce container stock were significantly influenced by container volume (Table 16).

All morphological characteristics and Qix values generally increased significantly with increasing container volume after one growing season in the field (Figure 24 and Appendix V). These results concur with numerous reports of other tree species but have not been well presented for black spruce in the past (Table 3).

The ANOVA, ANOCA and MLR results of this study suggest the following points.

1) Seedlings with root plugs of less than 90 cm^3 should not be outplanted in

the field. This small container stock suffered from reduction in growth in the greenhouse, and continued to suffer from it after outplanting. Such slow development in the field would be quite hazardous especially where heavy vegetative competition is present.

2) Seedlings with root plug volumes greater than 90 cm^3 may be outplanted because they grow significantly better in the field. The decision to use seedlings with 180 and 360 cm^3 root plugs will depend on the nature of the site and site preparation and on the cost of establishing container stock.

3) Additional morphological characteristics, such as dry weight, must be measured along with height and root collar diameter in order to evaluate outplant performance properly. Height and root collar diameter alone does not estimate seedling size and quality accurately.

Lateral root deformation and soil moisture may again be two possible reasons why root plug volume has affected the growth of black spruce after outplanting.

Lateral Root Deformation

The lateral root deformation, produced in the greenhouse production phase, was still present after one growing season in the field (Figure 24). Because of this, the restriction of the uptake of water and nutrients and the translocation of food reported by Harris (1967) may have continued after outplanting.

It is well known that seedling root deformities developed in containers have persisted for many years after outplanting (Arnott, 1972; deChamps, 1978; Grene, 1978).

These root deformities not only have persisted but have continued to affect seedling growth adversely for many years (Bergman et al, 1976; Rudolf, 1939; Stefansson, 1978).

Soil Moisture

Although the stock was removed from the containers before being planted, soil moisture conditions in the root plug may have been considerably different from that of the field soil. In this study the black spruce seedlings exploited the growing medium rather than the field soil and most of the roots were still growing within the plug at the end of the first growing season (Figure 24). These results concur with Endean (1972b) who found that white spruce did not extend many roots outside the container plug during the first year. Since the growing medium usually contains a high proportion of peat it can hold up to ten times its weight in moisture (Carlson, 1983; Klougard and Olsen, 1969; Tinus and McDonald, 1979). Rainfall would be more readily absorbed and retained longer in the growing medium than in the field soil. This would make conditions in a plug more favourable for root development throughout the growing season.

This hypothesis concurs with the results of many authors who found that seedlings with larger root plugs were generally more successful in establishing after outplanting, especially in poor site conditions (Davidson and Sowa, 1974; Karlsson and Kovats, 1974; Kellas and Edgar, 1979; McMinn, 1978, 1981; Scarratt, 1981; Solberg, 1978; Walker, 1981). Once seedlings have passed the critical establishment period, this soil moisture influence will eventually decline as the root systems exploit more of the surrounding soil.

Effects of Container Shape

The ANOVAs, ANOCAs and MLRs showed that the influence of container shape on the growth of black spruce was more pronounced at the end of the first growing season than at the end of the greenhouse production phase. After one growing season in the field the ANOVAs and ANOCAs showed that the height, root collar diameter, top, root and total dry weights and quality index (Qix) of black spruce container stock were significantly influenced by the shape of the root plug (Table 15). Seedlings with shallow, wide (1:2) root plugs grew significantly better than those with 1:3 or 1:4 shaped root plugs (Figure 24 and Appendix V).

The Student's t tests of the standardized b-coefficients in the MLR equations (Table 17) also showed these morphological characteristics and Qix values of black spruce container stock were significantly influenced by container diameter and depth (Table 16). At each container volume, all morphological characteristics and Qix values increased as container diameter increased (Appendix VI) and as container depth decreased (Appendix VII).

The ANOVA, ANOCA and MLR results of this study suggest the following points.

1) Black spruce seedlings should be grown for outplanting with shallow, wide root plugs that conform to the natural rooting pattern of this species.

2) Height and root collar measurements alone are not satisfactory for the evaluation of seedling outplant performance.

Lateral root deformation appears to explain why root plug shape affects the growth of black spruce after outplanting. Many authorities have stated that black spruce is a predominantly shallow rooted tree species with strongly developed lateral roots (Fowells, 1965; Harlow and Harrar, 1966; Preston, 1966). Because of its lateral rooting habit, black spruce appears to grow better in a container that allows for greater horizontal root development and less root deformation. The shallow, wide (1:2) shaped container seems to meet these objectives because root deformation was low and seedling growth was superior after one growing season in the field (Figure 24). This hypothesis concurs with the result of Biran and Eliassaf (1980a) who found that the growth of several species was stimulated when the shape of the container was matched with the natural root pattern of these species. They also found that mismatching container shape and root patterns retarded seedling growth.

GREENHOUSE AND OUTPLANTING COMPARISONS

Similarities

The growth results of the greenhouse production and outplanting phases showed that all morphological characteristics of black spruce were significantly influenced by container volume and shape. However the influence of container shape was less pronounced at the end of the greenhouse production phase.

Differences

1)The variance of each of the morphological characteristics was significantly ($P<0.001$) smaller at the end of the greenhouse production phase than after one growing season in the field (Table 18). The differences in the variances may have occurred because

a) the larger containers in the greenhouse were able to supply all growth requirements uniformly and were probably not fully utilized by the seedling, and b) there was greater variation in the environmental conditions in the field such as moisture, nutrients, shading and root competition from surrounding vegetation.

2)The seedling quality indices fell into three well defined groups which were easier to classify after one growing season in the field (Figure 38). The seedling quality indices after the greenhouse production phase were in less well defined groups and were more difficult to separate into classes. This is an important reason why greenhouse container studies should be carried on into the field to evaluate fully the effects of container volume and shape on seedling growth. Of all the container studies cited in the literature review only 60 per cent had been carried on into the field.

3)The top/root dry weight ratios were considerably different for seedlings grown in the greenhouse and after outplanting. Regardless of container volume or shape, the top/root ratio for seedlings in the greenhouse averaged 4:1, whereas those in the field averaged 2:1. Thus black spruce directs more energy into the production of roots during the first growing season after outplanting than in the optimal environment of the greenhouse. It has been well emphasized that seedling development and survival depends principally on the ability to produce new roots immediately after outplanting (Brix and van den Driessche, 1974; Kramer, 1960; Sutton, 1974, 1980; Tinus, 1974). Therefore it is extremely important to use a container system in the greenhouse production phased that does not inhibit root development in the field.

PREDICTION OF OPTIMUM CONTAINER VOLUME AND SHAPE

In order to predict an optimum container volume and shape for the production of black spruce it is essential to know what seedling quality standards are desired. Although there have been numerous reports on the stock quality of bareroot seedlings and other containerized seedlings, only Scarratt and Reese (1976); Roller (1976) and Hallet (1980) have attempted to quantify stock quality for containerized black spruce (Table 19). The results of this study suggest that their proposed morphological size classes either omit important characteristics or include seedling stock that is too small for successful growth after outplanting.

The stock quality standards given in Table 20 are proposed to evaluate the quality of black spruce at the end of a 16 week greenhouse production phase. These 'Sb-1' and 'Sb-2' standards have been devised by 1) selecting the top two classes (A and B) of black spruce stock that had grown exceptionally well after one growing season in the field (Figure 38), and 2) using the mean morphological characteristics of these two classes of seedlings after 16 weeks in the greenhouse as the proposed standards (Table 20).

The range of morphological characteristics of the 'Sb-1' and 'Sb-2' stock in Table 20 were plotted on the estimated response surfaces (Figures 13, 15, 17, 19, 21, 23) to determine the optimum container volume range at a 1:2 container shape necessary in producing this high quality 'Sb-1' and 'Sb-2' black spruce container stock.

The following optimum container volume ranges are summarized as follows.

1) A container volume range between 180 and 360 cm^3, at a 1:2 diameter/depth container shape, will produce containerized black spruce stock in the 'Sb-1'

TABLE 18. The variances of the morphological characteristics of seedlings grown in the greenhouse and after outplanting.

Morphological Characteristic	Greenhouse Phase	Outplanting Phase	F Ratio		F 0.005
Height	9.302	31.822	3.42	***	1.00
Root Collar Diameter	0.294	0.743	2.53	***	1.00
Top Dry Weight	0.161	2.158	13.40	***	1.00
Root Dry Weight	0.016	0.766	47.88	***	1.00
Total Dry Weight	0.265	5.055	19.07	***	1.00
Qix	0.004	0.084	21.00	***	1.00

Note: *** = $P(F>Fc) < 0.001$

TABLE 19. Existing specifications for the morphological characteristics of containerized black spruce after 16 weeks in a greenhouse.

Morphological Characteristic	CONTAINER STOCK SIZE [1]		
	SMALL	MEDIUM	LARGE
Height (cm)	7.5 - 15.0	15.1 - 20.0	20.1 - 25.0
Root Collar Diameter (mm)	1.0 - 1.5	1.6 - 2.0	2.1 - 3.0
Top/Root Dry Weight Ratio	6:1 - 3:1	6:1 - 3:1	6:1 - 3.1
Total Dry Weight (g)	0.35 - 0.75	0.76 - 1.20	1:21 - 1.50
Dickson's Seedling Quality Index	0.03 - 0.06	0.07 - 0.10	0.11 - 0.15

[1] Note: Specification guidelines from Scarratt, J.B. and K.H. Reese (1976), Roller, K.L. (1976) and Hallett, R.D. (1980).

TABLE 20. Proposed morphological characteristics for superior containerized black spruce after a 16 week greenhouse production phase.

Morphological Characteristic	Container Stock Size					
	Sb-2			Sb-1		
Height (cm)	13.0	-	15.0	15.1	-	20.0
Root Collar Diameter (mm)	2.5		3.0	3.1		3.5
Top/Root Dry Weight Ratio	3.51	-	4.00	3.00	-	3.50
Top Dry Weight (g)	0.70		1.10	0.90	-	1.20
Root Dry Weight (g)		0.30			0.50	
Total Dry Weight (g)	1.00	-	1.40	1.41		1.70
Root Plug Shape (Diam/Depth)		1:2			1:2	
Dickson's Seedling Quality Index (Qix)	0.13		0.19	0.20		0.25

size class.

2) A container volume range between 80 and 180 cm^3, at a 1:2 diameter/depth container shape, will produce containerized black spruce stock in the 'Sb-2' size class.

Even though the results of this study are based on a single production run in the greenhouse and a single growing season in the field, the very strong significance of the differences in the seedling quality classes (Figure 33) indicate that these results will be duplicated in future studies. It is possible to produce black spruce container stock of high quality which will continue to perform well after field outplanting.

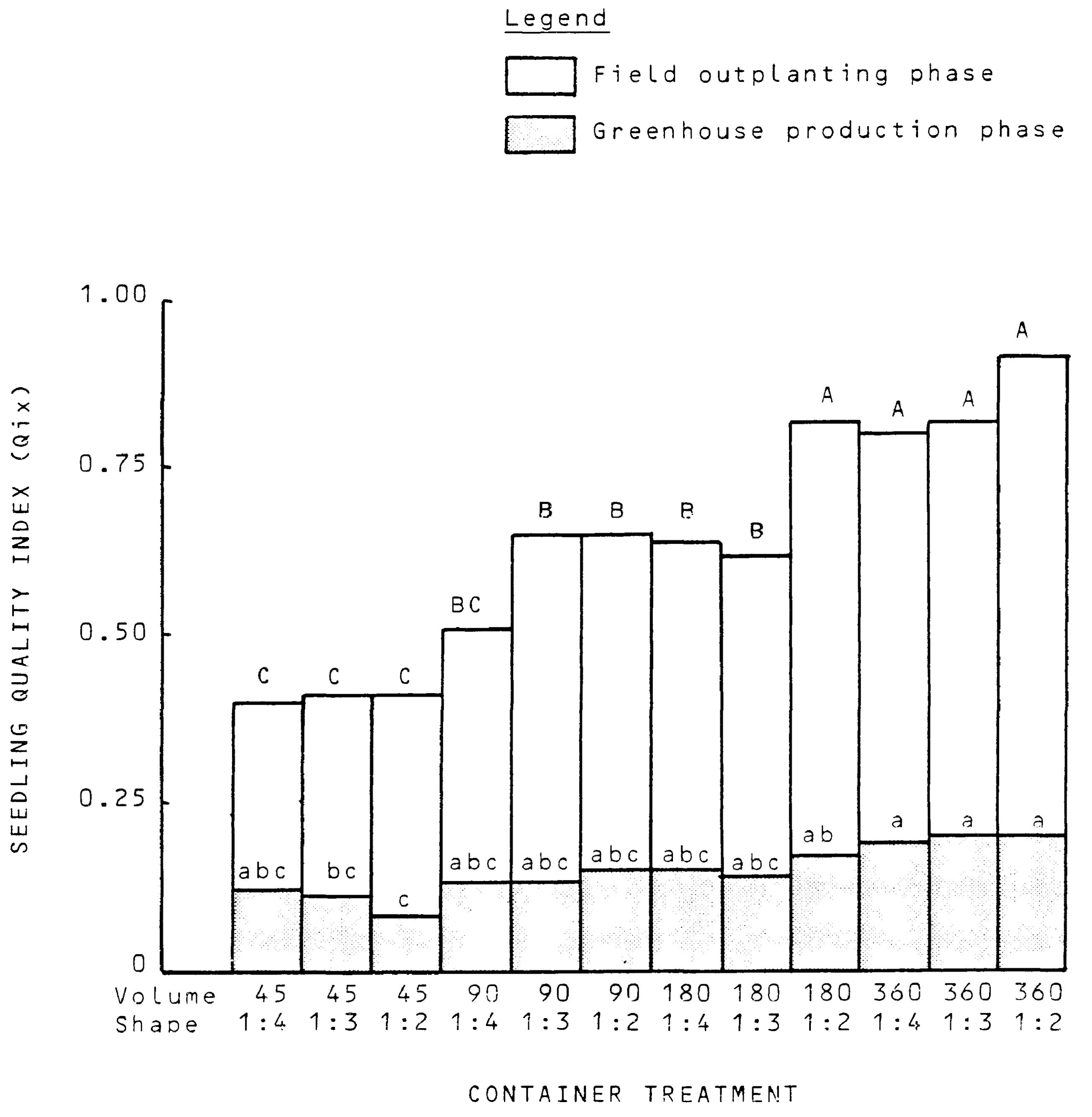

Figure 38. A comparison of the mean seedling quality indices of black spruce grown in the 12 container treatments after 16 weeks in the greenhouse and after one growing season in the field.

CONCLUSIONS

Container volume and shape are two environmental factors that should not be overlooked when growing containerized black spruce. Both factors have an important influence on seedling growth and stock quality in the greenhouse production phase and on subsequent establishment and growth after outplanting. The following main conclusions have been drawn from the results of this research:

1) Container volume has a strong influence on the morphological quality of black spruce in the greenhouse and after outplanting.
    a) Black spruce should never be grown in or outplanted from containers of less than 80 cm^3 since this limited volume is detrimental to seedling growth.
    b) Black spruce should be grown in containers that range from 80 to 180 cm^3 in volume if high quality ('Sb-2' size) stock is to be produced (Table 20).
    c) Black spruce should be grown in containers that range from 180 to 360 cm^3 in volume if superior quality ('Sb-1' size) stock is to be produced (Table 20).
2) Container shape also influences the morphological quality of black spruce both in the greenhouse production phase and after outplanting.
    a) The container shape should be shallow and wide, close to a 1:2 diameter/depth ratio, in order to match the natural widespread rooting pattern of black spruce.

b) Deep, narrow containers having a 1:3 or 1:4 diameter/depth ratio should be avoided.

3) The proposed morphological standards for containerized black spruce (Table 20) should be provisionally adopted until they are improved. Superior quality seedlings in the Sb-1 and Sb-2 classes defined in these standards may be more difficult to produce in the greenhouse but will improve the establishment and growth of black spruce trees free to grow in the field.

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APPENDICES

APPENDIX I

Latin Name Abbreviations

TABLE I-1. Latin names, their abbreviations and common names of species found in the literature review tables.

Latin name	Abbreviation	Common name
Acer saccharum March.	ACsc	Sugar maple
Avena sativa	AVs	Oats
Brassica pekinensis Rupr.	BRp	Chinese cabbage
Dodonea viscosa Jacq.	DOv	Varnish leaf
Eucalyptus regnans F. Muell.	EUr	Eucalyptus
Ficus retusa L.	FIr	Indian fig
Juglans nigra L.	JUn	Black walnut
Juniperus virgininana L. Hetzii	JNv	Hetz blue juniper
Lolium perene	LOp	Ryegrass
Picea abies (L.) Karst	PIa	Norway spruce
Picea glauca (Moench) Voss	PIg	White spruce
Picea mariana (Mill.) B.S.P.	PIm	Black spruce
Pinus banksiana Lamb.	PNb	Jack pine
Pinus caribaea Morelet	PNca	Caribbean pine
Pinus contorta Doug. var *latifolia* Engelm.	PNco	Lodgepole pine
Pinus elliottii Engelm.	PNe	Slash pine
Pinus ponderosa Laws.	PNp	Ponderosa pine
Pinus resinosa Ait.	PNr	Red pine
Pinus taeda L.	PNt	Loblolly pine
Pseudotsuga menziesii (Mirb.) Franco	PSm	Douglas fir
Pistacia lentiscus	PTl	Pistachio
Quercus falcata var. pagodifolia Ell.	Qf	Southern red oak
Zea maize L.	ZEm	Corn

APPENDIX II

MLR Patterns of Residuals For the Greenhouse and Field Data

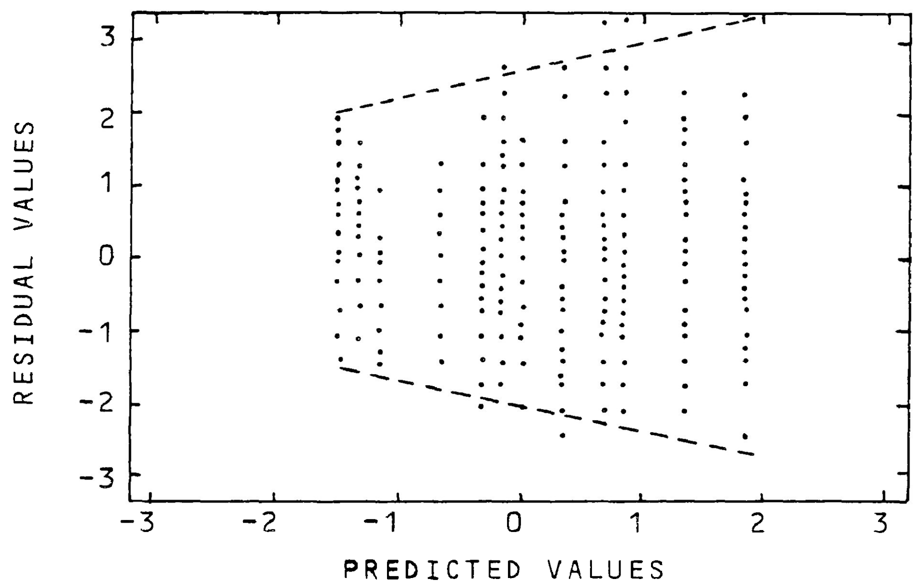

Figure II-1. Abnormal pattern of standardized residuals for the greenhouse total dry weight data.

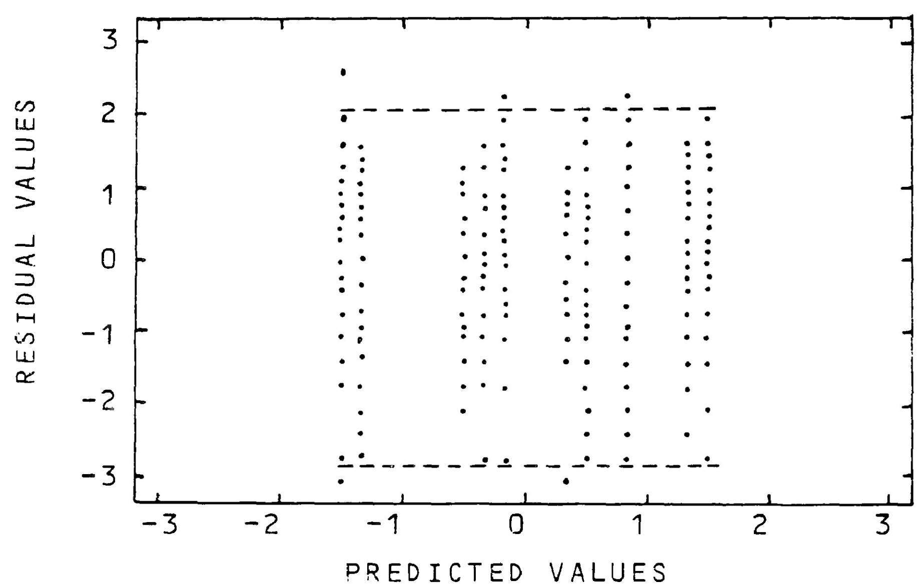

Figure II-2. Normal pattern of standardized residuals for the transformed greenhouse total dry weight data.

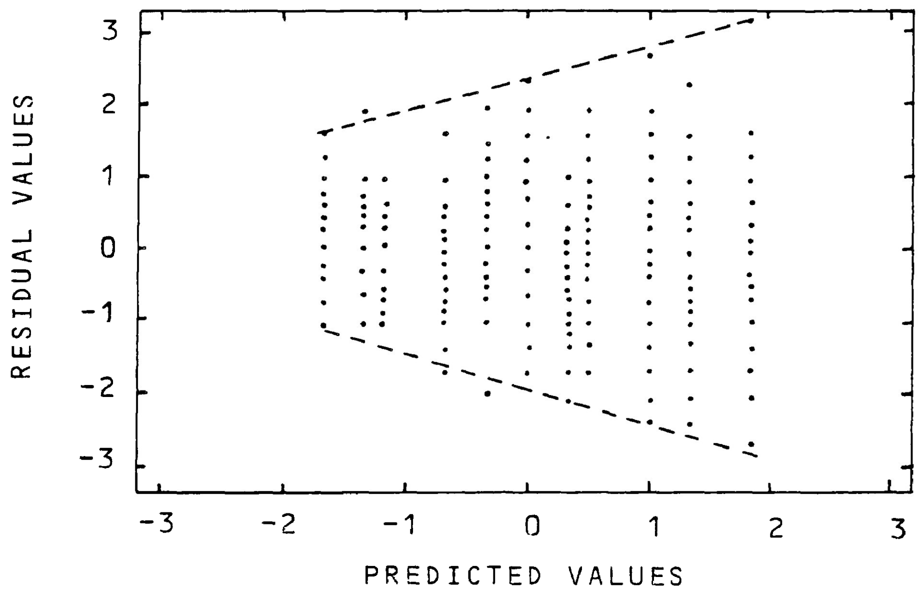

Figure II-3. Abnormal pattern of standardized residuals for the field total dry weight data.

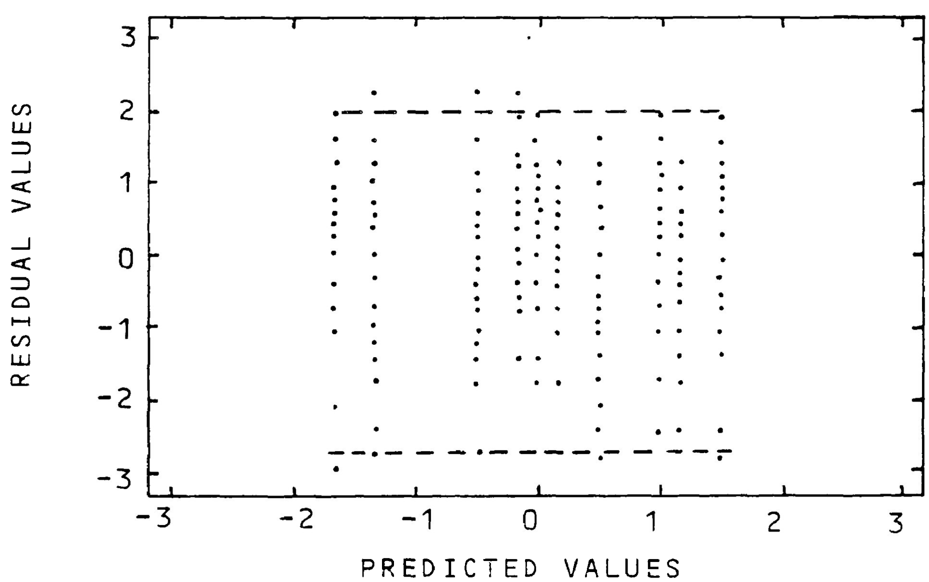

Figure II-4. Normal pattern of standardized residuals for the transformed field total dry weight data.

APPENDIX III

SNK Test Results
For the Greenhouse Data

TABLE III-1. Interaction table showing the treatment means for seedling height (cm) and SNK test results after 16 weeks in the greenhouse.

Container Dimension (Diam./Depth)	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	11.4	15.0	15.2	17.0	14.7	]	]
1:3	12.5	14.4	13.1	15.4	13.9	]	]
1:4	13.1	13.6	14.3	14.6	13.9	]	]
$\bar{x}$	12.4	14.3	14.2	15.7			
P=0.05	*	└─	─	─┘			
P=0.01		└─	─	─┘			
	└─	─	─┘				

TABLE III-2. Interaction table showing the treatment means for seedling root collar diameter (mm) and SNK test results after 16 weeks in the greenhouse.

Container Dimension (Diam./Depth)	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	2.5	3.2	3.3	3.3	3.1	]	]
1:3	2.8	2.9	2.8	3.3	3.0	]	]
1:4	2.7	2.8	2.9	3.2	2.9	]	]
$\bar{x}$	2.7	3.0	3.0	3.3			
P=0.05	└─	─	─┘	*			
P=0.01	└─	─	─┘				
		└─	─	─┘			

Note: Treatment means joined by a line are not significantly different.

A * indicates significant differences between treatment means at the corresponding level of P.

TABLE III-3. Interaction table showing the treatment means for seedling top dry weight (g) and SNK test results after 16 weeks in the greenhouse.

Container Dimension (Diam./Depth)	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	0.57	1.11	1.21	1.37	1.07	┐	┐
1:3	0.76	0.92	0.93	1.29	0.98	│	│
1:4	0.80	0.85	0.94	1.11	0.93	┘	┘
$\bar{x}$	0.71	0.96	1.03	1.26			
P=0.05	*	└──────	──────┘	*			
P=0.01	*	└──────	──────┘				
			└──────	──────┘			

TABLE III-4. Interaction table showing the treatment means for seedling root dry weight (g) and SNK test results after 16 weeks in the greenhouse.

Container Dimension (Diam./Depth)	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	0.13	0.26	0.31	0.38	0.27	┐	┐
1:3	0.20	0.25	0.25	0.38	0.27	│	│
1:4	0.23	0.23	0.28	0.36	0.28	┘	┘
$\bar{x}$	0.19	0.25	0.28	0.37			
P=0.05	*	└──────	──────┘	*			
P=0.01	*	└──────	──────┘	*			

Note: Treatment means joined by a line are not significantly different.

A * indicates significant differences between treatment means at the corresponding level of P.

TABLE III-5. Interaction table showing the treatment means for seedling total dry weight (g) and SNK test results after 16 weeks in the greenhouse.

Container Dimension (Diam./Depth)	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	0.70	1.36	1.51	1.74	1.33	]	]
1:3	0.97	1.16	1.18	1.67	1.25	]	]
1:4	1.02	1.08	1.22	1.47	1.20	]	]
$\bar{x}$	0.90	1.20	1.30	1.63	1.26		
P=0.05	*	└──	──┘	*			
P=0.01	└──	──┘ └──	──┘	*			

TABLE III-6. Interaction table showing the treatment means for seedling quality index (Qix) and SNK test results after 16 weeks in the greenhouse.

Container Dimension (Diam./Depth	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	0.08	0.15	0.17	0.20	0.15	]	]
1:3	0.11	0.13	0.14	0.20	0.15	]	]
1:4	0.12	0.13	0.15	0.19	0.15	]	]
$\bar{x}$	0.10	0.14	0.15	0.20			
P=0.05	*	└──	──┘	*			
P=0.01	└──	──┘ └──	──┘	*			

Note: Treatment means joined by a line are not significantly different.

A * indicates significant differences between treatment means at the corresponding level of P.

APPENDIX IV

The Growth Response in the
Greenhouse at Each Container
Volume and Depth

TABLE IV-1. The growth response of seedling height in cm at each container volume and depth.

Container Depth[1] (cm) [2]	Container Volume (cm^3) 45	90	180	360
5.8	11.4			
7.1	12.5			
7.9		15.0 ↑		
9.0	13.1 ↓			
9.4		14.3		
10.1			15.2 ↑	
11.4		13.6		
12.6				17.0 ↑
13.5			13.1	
15.7				15.4
15.8			14.3	
20.2 ↓				14.6

TABLE IV-2. The growth response of seedling root collar, diameter in mm at each container volume and depth.

Container Depth[1] (cm) [2]	Container Volume (cm^3) 45	90	180	360
5.8	2.5			
7.1	2.8 ×			
7.9		3.2 ↑		
9.0	2.7			
9.4		2.9		
10.1			3.2 ↑	
11.4		2.8		
12.6				3.3 ↑
13.5			2.8	
15.7				3.3
15.8			2.8	
20.2 ↓				3.1

[1] Note: See table 11 for corresponding container treatments

[2] Note: An increase is in the direction of the arrows

TABLE IV-3. The growth response of seedling top dry weight in g at each container volume and depth.

Container Depth[1] (cm)	Container Volume (cm³) 45	90	180	360
5.8 ↓[2]	0.57 ↓			
7.1	0.76			
7.9		1.11 ↑		
9.0	0.80			
9.4		0.92		
10.1			1.21 ↑	
11.4		0.85		
12.6				1.37 ↑
13.5			0.93	
15.7				1.29
15.8			0.94	
20.2				1.11

TABLE IV-4. The growth response of seedling root dry weight in g at each container volume and depth.

Container Depth[1] (cm)	Container Volume (cm³) 45	90	180	360
5.8 ↓[2]	0.13 ↓			
7.1	0.20			
7.9		0.26 ↑		
9.0	0.23			
9.4		0.25		
10.1			0.31 ↑	
11.4		0.23		
12.6				0.38 ↑
13.5			0.25	
15.7				0.38
15.8			0.28	
20.2				0.36

[1]Note: See table 11 for corresponding container treatments

[2]Note: An increase is in the direction of the arrows

TABLE IV-5. The growth response of seedling total dry weight in g at each container volume and depth.

Container Depth[1] (cm)	Container Volume (cm³) 45	90	180	360
5.8 ↓[2]	0.70 ↓			
7.1	0.97			
7.9		1.36 ↑		
9.0	1.02			
9.4		1.16		
10.1			1.51 ↑	
11.4		1.08		
12.6				1.74 ↑
13.5			1.18	
15.7				1.67
15.8			1.22	
20.2				1.47

TABLE IV-6. The growth response of seedling quality index at each container volume and depth.

Container Depth[1] (cm)	Container Volume (cm³) 45	90	180	360
5.8 ↓[2]	0.08 ↓			
7.1	0.11			
7.9		0.15 ↑		
9.0	0.12			
9.4		0.13		
10.1			0.17 ↑	
11.4		0.13		
12.6				0.20 ↑
13.5			0.14	
15.7				0.20
15.8			0.15	
20.2				0.19

[1]Note: See table 11 for corresponding container treatments

[2]Note: An increase is in the direction of the arrows

APPENDIX V

SNK Test Results
For the Outplanting Data

TABLE V-1. Interaction table showing the treatment means for seedling height (cm) and SNK test results after one growing season in the field.

Container Dimension (Diam./Depth)	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	21.1	23.1	25.3	27.0	24.1	]	]
1:3	20.2	25.2	24.9	24.6	23.7	]	]
1:4	19.7	23.0	23.7	24.0	22.6	]	]
$\bar{x}$	20.3	23.7	24.6	25.2			
P=0.05	*	└	─	┘			
P=0.01	*	└	─	┘			

TABLE V-2. Interaction table showing the treatment means for seedling root collar diameter (mm) and SNK test results after one growing season in the field.

Container Dimension (Diam./Depth)	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	3.4	4.5	4.6	5.3	4.4	]	]
1:3	3.5	4.3	4.2	4.8	4.2	]	]
1:4	3.7	3.7	4.3	4.8	4.1	]	]
$\bar{x}$	3.5	4.2	4.4	5.0			
P=0.05	*	└	┘	*			
P=0.01	*	└	┘	*			

Note: Treatment means joined by a line are not significantly different.

A * indicates significant differences between treatment means at the corresponding level of P.

TABLE V-3. Interaction table showing the treatment means for seedling top dry weight (g) and SNK test results after one growing season in the field.

Container Dimension (Diam./Depth)	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	1.69	3.24	4.20	5.00	3.53	*	*
1:3	1.73	3.13	3.03	4.18	3.02	]	]
1:4	1.69	2.36	3.17	3.79	2.75	]	]
$\bar{x}$	1.70	2.91	3.47	4.32			
P=0.05		*	*	*			
P=0.01		*	*	*			

TABLE V-4. Interaction table showing the treatment means for seedling root dry weight (g) and SNK test results after one growing season in the field.

Container Dimension (Diam./Depth)	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	1.03	1.80	2.18	2.80	1.95	*	*
1:3	1.02	1.71	1.66	2.14	1.63	]	]
1:4	1.04	1.43	1.77	1.96	1.55	]	]
$\bar{x}$	1.03	1.65	1.87	2.30			
P=0.05		*	*	*			
P=0.01		*	└────┘	*			

Note: Treatment means joined by a line are not significantly different.

A * indicates significant differences between treatment means at the corresponding level of P.

TABLE V-5. Interaction table showing the treatment means for seedling total dry weight (g) and SNK test results after one growing season in the field.

Container Dimension (Diam./Depth)	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	2.73	5.04	6.38	7.80	5.49	*	*
1:3	2.75	4.84	4.69	6.32	4.65	]	]
1:4	2.73	3.79	4.95	5.75	4.31		
$\bar{x}$	2.74	4.56	5.34	6.62			
P=0.05	*	*	*				
P=0.01	*	*	*				

TABLE V-6. Interaction table showing the treatment means for seedling quality index (Qix) and SNK test results after one growing season in the field.

Container Dimension (Diam./Depth)	Container Volume (cm^3) 45	90	180	360	$\bar{x}$	P=0.05	P=0.01
1:2	0.41	0.65	0.82	0.92	0.70	*	]
1:3	0.41	0.65	0.62	0.82	0.63	]	]
1:4	0.40	0.51	0.64	0.80	0.59		
$\bar{x}$	0.41	0.60	0.69	0.85			
P=0.05	*	*	*				
P=0.01	*	└────┘	*				

Note: Treatment means joined by a line are not significantly different.

A * indicates significant differences between treatment means at the corresponding level of P.

APPENDIX VI

The Growth Response After Outplanting at Each Container Volume and Diameter

TABLE VI-1. The growth response of seedling height in cm at each container volume and diameter.

Container Diameter[1] (cm)	Container Volume (cm^3) 45	90	180	360
2.54 [2]	19.7			
2.86	20.2			
3.18	21.1 ↓	23.0		
3.49		25.2 X		
3.81		23.1	23.7	
4.13			24.9	
4.76			25.3 ↓	24.0
5.40				24.6
6.03 ↓				27.0 ↓

TABLE VI-2. The growth response of seedling root collar diameter in mm at each container volume and diameter.

Container Diameter[1] (cm)	Container Volume (cm^3) 45	90	180	360
2.54 [2]	3.7 ↑			
2.86	3.5			
3.18	3.4	3.7		
3.49		4.3		
3.81		4.5 ↓	4.3	
4.13			4.2	
4.76			4.6 ↓	4.8
5.40				4.8
6.03 ↓				5.3 ↓

[1] Note: See table 11 for corresponding container treatments

[2] Note: An increase is in the direction of the arrows

TABLE VI-3. The growth response of seedling top dry weight in g at each container volume and diameter.

Container Diameter[1] (cm) [2]	Container Volume (cm^3) 45	90	180	360
2.54	1.69			
2.86	1.73			
3.18	1.69	2.36		
3.49		3.13		
3.81		3.24 ↓	3.17	
4.13			3.03	
4.76			4.02 ↓	3.79
5.40				4.18
6.03 ↓				5.00 ↓

TABLE IV-4. The growth response of seedling root dry weight in g at each container volume and diameter.

Container Diameter[1] (cm) [2]	Container Volume (cm3) 45	90	180	360
2.54	1.04 ↑			
2.86	1.02			
3.18	1.03	1.43		
3.49		1.71		
3.81		1.80 ↓	1.77	
4.13			1.66	
4.76			2.18 ↓	1.96
5.40				2.14
6.03 ↓				2.80 ↓

[1] Note: See table 11 for corresponding container treatments

[2] Note: An increase is in the direction of the arrows

TABLE VI-5. The growth response of seedling total dry weight in g at each container volume and diameter.

Container Diameter[1] (cm)[2]	Container Volume (cm^3) 45	90	180	360
2.54	2.73			
2.86	2.75			
3.18	2.73	3.79		
3.49		4.84		
3.81		5.04	4.95	
4.13			4.69	
4.76			6.38	5.75
5.40				6.32
6.03				7.80

TABLE VI-6. The growth response of seedling quality index at each container volume and diameter.

Container Diameter[1] (cm)[2]	Container Volume (cm^3) 45	90	180	360
2.54	0.40			
2.86	0.41			
3.18	0.41	0.51		
3.49		0.65		
3.81		0.65	0.64	
4.13			0.62	
4.76			0.82	0.80
5.40				0.82
6.03				0.92

[1]Note: See table 11 for corresponding container treatments

[2]Note: An increase is in the direction of the arrows

APPENDIX VII

The Growth Response After Outplanting at Each Container Volume and Depth

TABLE VII-1. The growth response of seedling height in cm at each container volume and depth.

Container Depth[1] (cm)	Container Volume (cm^3) 45	90	180	360
5.8 [2]	21.1 ↑			
7.1	20.2			
7.9		23.1		
9.0	19.7			
9.4		25.2 X		
10.1			25.3 ↑	
11.4		23.0		
12.6				27.0 ↑
13.5			24.9	
15.7				24.6
15.8			23.7	
20.2 ↓				24.0

TABLE VII-2. The growth response of seedling root collar diameter in mm at each container volume and depth.

Container Depth[1] (cm)	Container Volume (cm^3) 45	90	180	360
5.8 [2]	3.4			
7.1	3.5			
7.9		4.5 ↑		
9.0	3.7 ↓			
9.4		4.3		
10.1			4.6 ↑	
11.4		3.7		
12.6				5.3 ↑
13.5			4.2	
15.7				4.8
15.8			4.3	
20.2 ↓				4.8

[1] Note: See table 11 for corresponding container treatments

[2] Note: An increase is in the direction of the arrows

TABLE VII-3. The growth response of seedling top dry weight in g at each container volume and depth.

Container Depth[1] (cm)	Container Volume (cm^3) 45	90	180	360
5.8 [2]	1.69			
7.1	1.73 X			
7.9		3.24 ↑		
9.0	1.69			
9.4		3.13		
10.1			4.20 ↑	
11.4		2.36		
12.6				5.00 ↑
13.5			3.03	
15.7				4.18
15.8			3.17	
20.2 ↓				3.79

TABLE VII-4. The growth response of seedling root dry weight in g at each container volume and depth.

Container Depth[1] (cm)	Container Volume (cm^3) 45	90	180	360
5.8 [2]	1.03			
7.1	1.02			
7.9		1.80 ↑		
9.0	1.04 ↓			
9.4		1.71		
10.1			2.18 ↑	
11.4		1.43		
12.6				2.80 ↑
13.5			1.66	
15.7				2.14
15.8			1.77	
20.2 ↓				1.96

[1]Note: See table 11 for corresponding container treatments

[2]Note: An increase is in the direction of the arrows

TABLE VII-5. The growth response of seedling total dry weight in g at each container volume and depth.

Container Depth[1] (cm) [2]	Container Volume (cm^3) 45	90	180	360
5.8	2.73			
7.1	2.75			
7.9		5.04		
9.0	2.73			
9.4		4.84		
10.1			6.38	
11.4		3.79		
12.6				7.80
13.5			4.69	
15.7				6.32
15.8			4.95	
20.2				5.75

TABLE VII-6. The growth response of seedling quality index (Qix) at each container volume and depth.

Container Depth[1] (cm) [2]	Container Volume (cm^3) 45	90	180	360
5.8	0.41			
7.1	0.41			
7.9		0.65		
9.0	0.40			
9.4		0.65		
10.1			0.82	
11.4		0.51		
12.6				0.92
13.5			0.62	
15.7				0.82
15.8			0.64	
20.2				0.80

[1]Note: See table 11 for corresponding container treatments

[2]Note: An increase is in the direction of the arrows