PLANTING STOCK QUALITY, ROOT GROWTH CAPACITY, AND FIELD PERFORMANCE OF THREE BOREAL CONIFERS

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ABSTRACT

The influence of provenance and length of storage on root growth capacity (RGC) was determined in 2 + 0 jack pine (**Pinus banksiana** (Lamb.), 3 + 0 black spruce (**Picea mariana** (Mill.) B.S.P.), and 3 + 0 white spruce (**P. glauca** (Moench) Voss.). All plants were random samples of spring-lifted production-run planting stock raised by the Ontario Ministry of Natural Resources and used in Canadian Forestry Service stand establishment trials in 1972 and 1973. Except for some fresh- and field-stored stock used in the first two RGC tests in 1972, all stock was cold stored, then withdrawn as required after specified storage periods of up to 5 months. The number of roots that elongated in solution culture during the 21-day tests were counted on a total of 3594 trees.

RGC differed greatly between the two test environments, but common to both were: a rapid decline with increasing length of storage; marked differences between species in the order jack pine > black spruce > white spruce; and substantial differences between provenances, the more northerly provenances showing higher RGC. The field significance of these results is examined in terms of survival and growth up to the fourth growing season after outplanting. Several correlations were significant, but relationships were generally obscured by great within-treatment variability.

INTRODUCTION

The tree whose root system produces new root growth within a few days after outplanting will probably survive and grow as well as site conditions permit, but if root growth is delayed, outplant growth will be reduced. Without root growth, mortality is certain. Field performance in relation to root growth capacity is central to the question of planting stock quality and its prediction (Sutton, 1979).

Part A of this three-part paper is an account of tests of root growth capacity (RGC) (Stone and Jenkinson, 1970; Burdett, 1979) on sub-samples of planting stock used in plantation establishment trials in Ontario in 1972 and 1973. In Part B, first-year through fourth-year field performance data from sequential extended planting season outplantings are discussed. In Part C, correlations between RGC and field performance are examined.

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PART A: ROOT GROWTH CAPACITY (RGC)

The physiological state of a tree is intimately dependent on plant growth regulators as well as on nutrition, internal water status, and carbohydrate reserves. This physiological state affects the ability of a tree to augment its root system after outplanting. Attempts to estimate this ability in planting stock have been based on the amount of root growth made during a specified period in a standard environment. Such an estimate has been variously termed "root-regenerating potential" or RRP (cf. Stone, 1955; Stone *et al.*, 1962), "root-regenerating capacity" (cf. Krugman and Stone, 1966), and "root growth capacity" or RGC (cf. Stone and Jenkinson, 1970; Burdett, 1979). The latter term (RGC) avoids using the word "regenerating" in a sense at variance with its morphogenetic meaning.

Thus RGC cannot be determined directly. In spite of some recent contrary indications relating to fresh (not cold-stored) Southern pine stock (cf. Blair and Cech, 1974), the seemingly capricious correlation between planting stock morphology and quality has long been the bane of the regeneration forester. Wakeley (1948) summed up the situation very well: "Grades applied to nursery stock can be useful only so far as they distinguish seedlings with a high capacity for survival and growth after planting from those with a low capacity. . . . In the middle 1930s . . . evidence developed that . . . morphological grades coincided less well with true grades than had at first appeared, and were therefore resulting in the use of many seedlings foredoomed to die and the rejection of many seedlings able to survive." Wakeley dealt with the Southern pines, but he noted that a similar situation may occur in other regions.

Materials and Methods

In 1972 and 1973, production-run 2 + 0 jack pine (*Pinus banksiana* Lamb.), 3 + 0 black spruce (*Picea mariana* (Mill.) B.S.P.), and 3 + 0 white spruce (*Picea glauca* (Moench) Voss) planting stock was obtained from the Ontario Ministry of Natural Resources Swastika nursery (48°0.1'N, 80°22'W) for stand establishment studies in the boreal forest of Ontario. The studies included plantings both during the regular (spring) planting season and through an extended (summer through autumn) planting season. In both years, the stock used had been spring-lifted, graded, bundled, and bagged during normal operations. Then, except for the first batch of stock used fresh or after 4 weeks of field storage in 1972, the stock was immediately put into cold storage at the nursery. In both years, batches of 2000 trees per species were withdrawn from storage every 2 weeks through the growing season. Alternate batches were randomly subsampled by the bundle to provide a grand total of 3594 trees for RGC testing.

Samples of both provenances (Ontario Ministry of Natural Resources seed zones 3E and 4E) used in the conventional spring planting experiments (to be reported elsewhere) were taken as soon as the stock reached the planting site, and were removed within 24 hours to the Great Lakes Forest Research Centre where RGC and moisture contents were determined. In 1972, this planting stock fortuitously remained heeled in at the planting site for more than a month and thus could be resampled and tested, together with 4E stock newly taken from cold storage, in the second RGC test. Thereafter in 1972 throughout the extended planting season studies, only the 4E provenance was used. In 1973, 3E and 4E stock were compared in the first test; only 4E stock was used thereafter.

For RGC determination, the trees were washed clean and examined (in vain) for the presence of freshly elongated roots, then grown in 0.1 strength Arnon and Hoagland's nutrient solution (Hewitt, 1966), both in a laboratory growth tank (T) and in an EY15 Plant Growth Cabinet (Controlled Environment Ltd) (C). The solution, changed weekly, was circulated continuously and aerated to maintain full atmospheric partial pressure of oxygen. The total volumes circulating in the tank and chamber were 200 *l* and 230 *l,* respectively. The temperature of the nutrient solution was held constant at 21 ± 1°C. The ambient temperatures were 21-27°C (T) and 21°C (C). An 18-hour photoperiod was provided with fluorescent and incandescent lamps which at plant height gave approximately 21 000 lux (T) and 32 000 lux (C), respectively. The trees were removed after 21 days, and as soon as possible all fresh white roots were counted, short roots and long roots (*sensu* Sutton, 1969) separately. Trees were held in cool storage until root counts could be made: this presented few difficulties in 1973, but in 1972 lengthy delays resulted in deterioration of samples and introduced some imprecision with consequent loss of information.

Orthogonality, i.e., statistically independent equally replicated treatments, was not possible because of resource limitations.

Morphological and Nutritional Characteristics of the RGC Stock

Morphologically, within species, the stock did not differ significantly between RGC tests. The mean heights of the stock tested in 1972 were 17.6 cm, 25.2 cm, and 20.8 cm for jack pine, black spruce, and white spruce, respectively. The comparable values for the 1973 stock were 15.0 cm, 26.3 cm, and 16.2 cm.

With the exception of jack pine, top weight, mean top and root dry weights were significantly (P.01) greater in 1972 stock of all three species than in 1973 stock. For jack pine, black spruce, and white spruce, respectively, shoot dry weights (g) averaged 3.54, 3.01, and 3.03 in 1972 and 2.15, 2.96, and 2.53 in 1973; and root dry weights (g) averaged 0.68, 0.85, and 0.88 in 1972, and 0.44, 0.74, and 0.57 in 1973. Variations between batches within seasons were not significant. Weights varied more than did heights, coefficients of variation averaging 57% in 1972 and 49% in 1973 for top weight and 65% in 1972 and 56% in 1973 for root weight, approximately double the variation in top height.

Some differences in macronutrient concentration were statistically significant (Table 1), but consistent trends were not detected.

RESULTS AND DISCUSSION

There were great differences between the two test situations in the number of roots showing new growth (Tables 2, 3). Although made as similar as was practical, the two environments differed in important respects, notably in light intensity and ambient relative humidity, which were higher in the growth chamber than in the growth tank. Obviously, test conditions would have to be highly standardised in all significant factors before absolute values from one test could be directly compared with those from another.

For both spruces in the first RGC test in 1972 and again in 1973, complexity is further indicated by significantly higher numbers of newly elongated short roots in the growth tank than in the growth chamber. For all three species in both years the reverse

TABLE 1—Macronutrient concentrations in foliage of concomitant samples at the beginning of specified RGC tests

Year	Test	N	P	K	Ca	Mg
		(%)	(%)	(%)	(%)	(%)
				Jack pine		
1972	1	1.93a	—	.47b	.42a	.057b
1973	1	1.90a	.17a	.72a	.39a	.092a
1973	5	1.89a	.16a	.66a	.40a	.075a
1973	6	1.61b	.16a	.67a	.45a	.081a
				Black spruce		
1972	1	1.58a	—	.44b	.58b	.060a
1973	1	1.33b	.13a	.48ab	.59b	.068a
1973	5	1.35ab	.14a	.56a	.77ab	.054a
1973	6	1.52ab	.14a	.55ab	.75a	.068a
				White spruce		
1972	1	1.67ab	—	.34b	.64a	.047b
1973	1	1.56b	.14a	.37b	.97a	.072a
1973	5	1.80ab	.14a	.54a	.79a	.048b
1973	6	1.80a	.16a	.53a	.94a	.052ab

NOTE: For each species and nutrient separately, values lacking a common following letter differ significantly ($P \leq 0.05$).

was true for long roots (Table 4). Furthermore, in both years these relationships changed markedly during successive tests. In general, as the duration of storage increased, the growth chamber became better than the growth tank for short root growth.

Notwithstanding the great variability and uncertainties associated with individual absolute values, the main trends, common to both test situations, were clear. These were related to storage period, species, provenance, and type of storage.

Storage Period

In both years, growth of both short and long roots declined markedly with increasing length of storage (Table 2). In 1972, new root growth essentially ceased in trees that had been stored for a minimum of 21 weeks. In 1973, root growth virtually ceased after 12 weeks.

Species

New root growth was greatest in jack pine, intermediate in black spruce, and least in white spruce. The decline in root growth with increasing length of storage was common to all three species, but the rate of change was least in white spruce, greatest in jack pine.

Provenance

Comparative data are few but illuminating. Differences between the two provenances were large (Table 5). With but one exception, more short roots per tree elongated in the more northerly provenance 3E, in both years in both test environments, than did in provenance 4E. For short roots, six of the twelve ratios exceed 2. Four weeks of field storage in 1972 seemed to depress RGC to a greater degree in 3E stock than in 4E stock (cf. Table 3).

TABLE 2—Mean numbers of short roots and long roots per 4E tree newly elongated during 21-day RGC test, by species, test environment, and year of test. Tests 1 through 6 are sequential, storage duration increasing by 4 weeks with each succeeding test

Year	Root type	Species	Test environment	RGC test no. 1	2	3	4	5	6
1972	short	jP	tank	(297)*	181	103	65	26	14
			chamber	(265)	—†	124	109	124	0
		bS	tank	(401)	95	26	65	—	35
			chamber	(148)	—	42	108	—	+‡
		wS	tank	(86)	9	11	10	1	8
			chamber	(20)	—	8	17	22	+
	long	jP	tank	(0.6)	7.8	1.7	0.9	0.0	0.0
			chamber	(15.8)	—	4.5	3.3	4.2	0.0
		bS	tank	(1.0)	4.1	0.7	2.1	—	0.3
			chamber	(5.6)	—	0.4	3.9	—	0.0
		wS	tank	(0.8)	2.0	0.6	0.2	0.0	0.2
			chamber	(1.2)	—	0.4	0.1	0.4	0.0
1973	short	jP	tank	122	9	32	3	1	0
			chamber	239	265	135	1	0	0
		bS	tank	56	11	34	6	+	0
			chamber	36	93	49	3	1	0
		wS	tank	14	6	5	3	+	1
			chamber	6	14	3	0	0	0
	long	jP	tank	4.9	0.4	0.4	0.1	0.0	0.0
			chamber	18.8	24.6	5.0	0.0	0.0	0.0
		bS	tank	1.4	1.0	0.3	0.0	+	0.1
			chamber	8.2	22.9	2.4	0.0	0.0	0.0
		wS	tank	0.4	0.5	0.0	+	0.0	2.8
			chamber	2.0	1.3	0.2	0.0	0.0	0.0

* Figures in parentheses indicate field-stored stock; all other stock was cold-stored between spring-lifting and RGC testing.

† Not tested.

‡ Trace.

Type of Storage

First, a caution is in order: "cold storage" and "field storage" are not single, characterised treatments. Storage treatments may differ very widely both in their component factors and in the effects produced. For example, the effect of any given storage "treatment" on the physical and physiological condition of the stock will depend on a host of interacting factors, including the condition of the trees when entering storage, size of trees, size of bundle or package, etc., rate of cooling, plant moisture relationships, light conditions during storage, and perhaps rates of warming of plants leaving storage.

The fact that the decrease between the first and second tests in number of short roots showing new growth was much greater in 1972 than in 1973 suggests that cold storage, even for a few days, depresses new root growth. Buckley and Lovell (1974) found significant decreases in survival and vigour among 1-year-old seedlings of Sitka spruce (*Picea sitchensis* (Bong.) Carr) after cold storage.

TABLE 3—Mean numbers of short roots and long roots per tree newly elongated during 21-day RGC test, by species and provenance, test environment, test number, and year of testing

				RGC test no.				
				1		2		
Year	Root type	Species	Test environment	3E*	4E*	3E*	4E*	4E*
1972	short	jP	tank	(824)**	(297)	(88)	(135)	181
			chamber	(1036)	(265)	—	—	—
		bS	tank	(219)	(401)	(166)	(106)	95
			chamber	(273)	(148)	—	—	—
		wS	tank	(95)	(86)	(4)	(14)	9
			chamber	(166)	(20)	—	—	—
	long	jP	tank	(0.3)	(0.6)	(4.7)	(5.7)	7.8
			chamber	(26.1)	(15.8)	—	—	—
		bS	tank	(1.1)	(1.0)	(3.1)	(3.3)	4.1
			chamber	(22.6)	(5.6)	—	—	—
		wS	tank	(0.2)	(0.8)	(0.6)	(0.5)	2.0
			chamber	(1.4)	(1.2)	—	—	—
1973	short	jP	tank	235	122	—	—	—
			chamber	286	239	—	—	—
		bS	tank	77	56	—	—	—
			chamber	171	36	—	—	—
		wS	tank	28	14	—	—	—
			chamber	21	6	—	—	—
	long	jP	tank	8.1	4.9	—	—	—
			chamber	19.9	18.8	—	—	—
		bS	tank	1.0	1.4	—	—	—
			chamber	36.8	8.2	—	—	—
		wS	tank	0.4	0.4	—	—	—
			chamber	5.7	2.0	—	—	—

* Provenances.
** Parentheses indicate field-stored stock.

The effect of cold storage on ponderosa pine (*Pinus ponderosa* Laws.) seedlings was found by Stone and Jenkinson (1971) to depend very much on the time of lifting. In the present study, this was not a variable, as lifting in both years took place during the regular spring-lifting period.

Planting Stock Morphology and RGC

Various morphological characteristics of the planting stock tested for RGC were examined for correlations with new root growth. Separately for each species, storage period, test environment, and root type, correlations between RGC and each of shoot length, shoot dry weight, root dry weight, and root collar diameter, were examined. The correlation between short root and long root growth was conveniently determined at the same time.

Significant correlations did occur (Tables 6 and 7). The major effect of the test environment on the results is again clear, for, although the two environments gave similar indications in 73% of the comparisons possible in the 1972 data, and 70%

TABLE 4—Mean root growth per tree in growth tank as a percentage of that in growth chamber

Year	Root type	Species	RGC test no. 1	2	3	4	5	6
			(%)	(%)	(%)	(%)	(%)	(%)
1972	short	jP	(112)*	—†	83	60	21	—
		bS	(271)	—	62	60	—	—
		wS	(430)	—	137	59	5	—
	long	jP	(4)	—	38	27	—	—
		bS	(18)	—	175	54	—	—
		wS	(67)	—	150	200	—	—
1973	short	jP	51	12	24	300	—	—
		bS	156	12	69	200	—	—
		wS	233	43	167	—	—	—
	long	jP	26	2	8	—	—	—
		bS	17	4	12	—	—	—
		wS	20	38	—	—	—	—

* Parentheses indicate field storage. Other stock cold stored.
† No data.

TABLE 5—Mean new root growth per tree during the first 21-day RGC test by provenance 3E stock as a ratio of that in provenance 4E stock

Year	Species	Short roots: Tank	Short roots: Chamber	Long roots: Tank	Long roots: Chamber
1972	jP	2.8	3.9	0.5	1.7
	bS	0.5	1.8	1.1	4.0
	wS	1.1	8.3	0.3	1.2
1973	jP	1.9	1.2	1.7	1.1
	bS	1.4	4.8	0.7	4.5
	wS	2.0	3.5	1.0	2.8

in the 1973 data, in only 12% of cases in 1972 and 5% in 1973 did the two test environments both indicate a significant correlation: in the great majority of cases where the different test environments gave similar indications this resulted from non-significance in both correlations.

The number of significant correlations varied with species, in the same order as RGC: jack pine most, white spruce least.

No one morphological variable was clearly better correlated with RGC than were any of the others. Again, however, the variability of the stock is emphasised: the greater the "noise", the stronger must be a signal before it is detectable.

Table 6. Significance of correlations between certain morphological variables and new root growth in jack pine, black spruce, and white spruce planting stock spring-lifted in 1972 and stored for 0 to 5 months before placement in growth tank (T) or growth chamber (C) for 21-day test of root growth capacity (RGC).

	Short root RGC												Long root RGC											
	Months of storage before RGC test																							
	0		1		2		3		4		5		0		1		2		3		4		5	
Variable	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
1972																								
Jack pine																								
Shoot length	[*]†	[*]	**	–‡	–**§	ns¶	ns	ns	ns	ns	ns	–	[ns]	[*]	**	–	**	*	ns	ns	–	ns	–	–
Shoot dry weight	[ns]	[ns]	**	–	**	ns	**	ns	ns	ns	*	–	[ns]	[ns]	*	–	ns	*	*	ns	–	ns	–	–
Root dry weight	[ns]	[ns]	**	–	*	*	**	ns	*	ns	*	–	[ns]	[ns]	[ns]	–	*	*	ns	ns	–	ns	–	–
Root collar diam	[ns]	[*]	ns	–	*	*	**	ns	ns	ns	ns	–	[ns]	[*]	ns	–	*	**	ns	ns	–	ns	–	–
Short roots	–	–	–	–	–	–	–	–	–	–	–	–	[ns]	[**]	ns	–	**	**	**	**	–	**	–	–
Black spruce																								
Shoot length	[ns]	[ns]	**	–	**	ns	ns	ns	–	–	ns	–*	[ns]	[ns]	**	–	ns	ns	ns	ns	–	–	ns	–
Shoot dry weight	[**]	[ns]	ns	–	ns	ns	**	**	–	–	ns	ns	[ns]	[ns]	*	–	ns	ns	**	*	–	–	ns	–
Root dry weight	[**]	[ns]	ns	–	ns	ns	**	**	–	–	ns	ns	[ns]	[ns]	**	–	ns	ns	*	ns	–	–	ns	–
Root collar diam	[**]	[ns]	ns	–	ns	ns	*	*	–	–	ns	ns	[ns]	[ns]	*	–	ns	ns	ns	ns	–	–	ns	–
Short roots	–	–	–	–	–	–	–	–	–	–	–	–	[ns]	[ns]	ns	–	ns	ns	**	**	–	–	*	–
White spruce																								
Shoot length	[ns]	[ns]	**	–	ns	ns	ns	ns	ns	ns	ns	ns	[ns]	[ns]	**	–	ns	ns	ns	ns	–	ns	ns	–
Shoot dry weight	[*]	[ns]	ns	–	ns	–	ns	ns	ns	ns	ns	ns	[ns]	[ns]	ns	–	ns	–	ns	ns	–	ns	ns	–
Root dry weight	[**]	[ns]	ns	–	ns	–	ns	ns	ns	**	ns	ns	[ns]	[ns]	ns	–	ns	–	ns	ns	–	*	ns	–
Root collar diam	[*]	[ns]	*	–	ns	–	ns	ns	ns	ns	ns	ns	[ns]	[ns]	ns	–	ns	–	ns	ns	–	ns	ns	–
Short roots	–	–	–	–	–	–	–	–	–	–	–	–	[ns]	[ns]	ns	–	ns	–	*	**	–	*	**	–

*, ** Correlation coefficient significant (P. 05), (P. 01).
† Brackets indicate field stored stock, other stock cold stored.
‡ No data.
§ Negative correlation.
¶ Non-significant correlation.

Table 7. Significance of correlations between certain morphological variables and new root growth in jack pine, black spruce, and white spruce planting stock spring-lifted in 1973 and stored for 0 to 5 months before placement in growth tank (T) or growth chamber (C) for 21-day test of root growth capacity (RGC).

	Short root RGC												Long root RGC											
	Months of cold storage before RGC test																							
	0		1		2		3		4		5		0		1		2		3		4		5	
Variable	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
1973																								
Jack pine																								
Shoot length	**	ns†	ns	ns	ns	ns	ns	ns	ns	–‡	–	–	**	ns	ns	ns	ns	ns	ns	ns	–	–	–	–
Shoot dry weight	**	ns	ns	**	ns	ns	ns	ns	ns	–	–	–	**	ns	ns	**	ns	ns	ns	ns	–	–	–	–
Root dry weight	**	**	ns	**	ns	ns	ns	ns	na	–	–	–	**	**	ns	*	ns	ns	ns	ns	–	–	–	–
Root collar diam	**	ns	ns	**	ns	ns	ns	ns	ns	–	–	–	**	ns	ns	*	ns	ns	ns	ns	–	–	–	–
Short roots	–	–	–	–	–	–	–	–	–	–	–	–	**	**	**	*	**	**	ns	**	–	–	–	–
Black spruce																								
Shoot length	ns	ns	ns	ns	ns	ns	ns	–*§	ns	ns	ns	–	ns	ns	ns	ns	ns	ns	–	–	ns	–	–	–
Shoot dry weight	ns	ns	*	ns	*	**	ns	ns	ns	ns	ns	–	ns	ns	ns	ns	*	ns	–	–	ns	–	–	–
Root dry weight	ns	ns	ns	ns	**	*	ns	ns	ns	ns	ns	–	ns	ns	ns	*	*	ns	–	–	*	–	–	–
Root collar diam	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	–	ns	ns	ns	*	ns	ns	–	–	ns	–	–	–
Short roots	–	–	–	–	–	–	–	–	–	–	–	–	**	**	**	**	**	–	–	–	ns	–	–	–
White spruce																								
Shoot length	ns	ns	ns	ns	ns	ns	ns	–	ns	–	ns	–	ns	ns	ns	ns	–	ns	–	–	–	–	ns	–
Shoot dry weight	ns	ns	ns	*	ns	ns	ns	–	ns	–	ns	–	ns	ns	ns	*	–	ns	ns	–	–	–	–**	–
Root dry weight	ns	ns	ns	*	ns	ns	ns	–	ns	–	ns	–	ns	ns	ns	ns	–	ns	ns	–	–	–	–*	–
Root collar diam	ns	ns	ns	*	ns	ns	ns	–	ns	–	–*	–	ns	ns	ns	ns	–	ns	ns	–	–	–	–**	–
Short roots	–	–	–	–	–	–	–	–	–	–	–	–	**	**	**	**	–	**	**	–	–	–	*	–

*, ** Correlation coefficient significant (P. 05), (P. 01)

† Non-significant correlation.

‡ No data

§ Negative correlation.

PART B: FIELD PERFORMANCE

The RGC tests described in Part A were conducted on subsamples of planting stock used in sequential outplantings through the growing season. The survival and growth data available for these plantings, for the first through fourth growing seasons in the field, provide the opportunity to assess the usefulness of RGC as a predictor of performance. Since performance reflects the resultant interaction between out-plants and the field environment, the salient features of the field experimentation must be stated.

Sequential Outplantings

In each of 1972 and 1973, production-run planting stock, as described in Part A, but of one provenance (4E) only, was outplanted on three sites at intervals of 2 weeks beginning about 1 July and continuing into late October. This gave a total of nine plantings, stock being withdrawn from cold storage as required. Each of the nine sequential outplantings on three sites with three species received three levels of NPK fertilisation (none, "low", and "high" suffice to identify them in the present context) at the time of outplanting, and two levels of soil cultivation in a factorial design. The 20-tree plots replicated five times per treatment gave 600 trees per species per site or 5400 per outplanting and a total of 48 600 trees for each year's trial.

RESULTS AND DISCUSSION

Results of these outplantings, together with those of the 1971 replicate, will be reported in greater detail elsewhere. An indication of the main trends only is necessary for the present purpose.

Although there were differences in performance between sites within years, these were minor, and trends were consistent. Thus, within years, the results averaged over the three sites would seem to be a reasonable expression of performance. So averaged, the mean annual height increment for each of the first four growing seasons in the field, and the survival at the end of that period are illustrated by species and fertiliser treatment for the 1972 (Fig. 1) and 1973 (Fig. 2) out-plantings. Clearly: survival declined precipitously in stock that had been stored for more than 2 months; fertilisation at outplanting decreased survival and did not improve growth of survivors; survival percentage and growth of survivors were strongly correlated; and within the period of observation, trees that started poorly continued poorly. Also, the expected superiority of jack pine height growth during this period in relation to that of the spruces was fully substantiated.

For certain outplantings, average performance data relate directly to specific RGC tests (Tables 8 and 9).

PART C: STOCK QUALITY CRITERIA

Some difficulty in defining performance was noted in Part B. Similarly, root growth is not easily defined. Currently used quantifiers of root and root system behaviour — root number, root length, root number and root length combined, root weight, root surface area, water extraction, description, etc. — are all seriously deficient in one way or another (Pearson, 1974). The problem is aggravated when the values obtained in

TABLE 8—Survival after 4 growing seasons in the field of sequentially outplanted jack pine (jP), black spruce (bS), and white spruce (wS), by year of planting, for the untreated control condition, averaged over three sites

Outplanting no.	RGC test	Length of storage	1972 jP	1972 bS	1972 wS	1973 jP	1973 bS	1973 wS
		(months)	(%)	(%)	(%)	(%)	(%)	(%)
1	2	1	96.0	90.7	90.7	93.3	76.8	74.8
3	3	2	81.5	85.2	82.3	97.5	77.7	85.0
5	4	3	63.0	25.3	24.8	65.3	34.5	26.7
7	5	4	41.5	9.5	32.8	—	—	—
9	6	5	—†	—	—	—	—	—

† Negligible survival.

TABLE 9—Mean total height after 4 growing seasons in the field of sequentially outplanted jack pine (jP), black spruce (bS), and white spruce (wS), by year of planting, for the untreated control, averaged over three sites

Outplanting no.	RGC test	Length of storage	1972 jP	1972 bS	1972 wS	1973 jP	1973 bS	1973 wS
		(months)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
1	2	1	116.7	65.6	51.7	88.5	34.3	23.2
3	3	2	88.5	42.1	35.7	70.3	29.6	19.7
5	4	3	68.3	20.2	17.6	53.0	22.2	14.5
7	5	4	59.0	25.9	17.4	—	—	—
9	6	5	—†	—	—	—	—	—

† Insufficient data.

RGC tests are apparently highly dependent on the test environment (cf. Table 2).

In the RGC studies reported here, neither set of values — growth tank or growth chamber — can be said to be more valid than the other, and although one might imagine the growth chamber data to be superior on the grounds that they were produced in a supposedly more highly controlled environment, these data were in fact more variable than were those produced in the less sophisticated growth tank. Nor is averaging the two sets of data feasible, there being different cell numbers and missing data complications. The basic data available for the examination of correlative relationships are given in Table 10.

Some correlations between RGC and field performance are significant (Table 11). For example, jack pine RGC, as estimated by 1972 growth tank data, correlated significantly with survival after 4 growing seasons in the field ($P \leq 0.05$), third year height increment ($P \leq 0.05$), and fourth year height increment ($P \leq .01$). Also, the 1972 jack pine growth tank data for long root RGC were significantly correlated with second year height increment ($P \leq 0.05$), and with total height at the end of the fourth growing season in field ($P \leq .05$). As well, long root RGC in white spruce, as estimated by the 1972 growth tank data, correlated significantly ($P \leq 0.05$), with first,

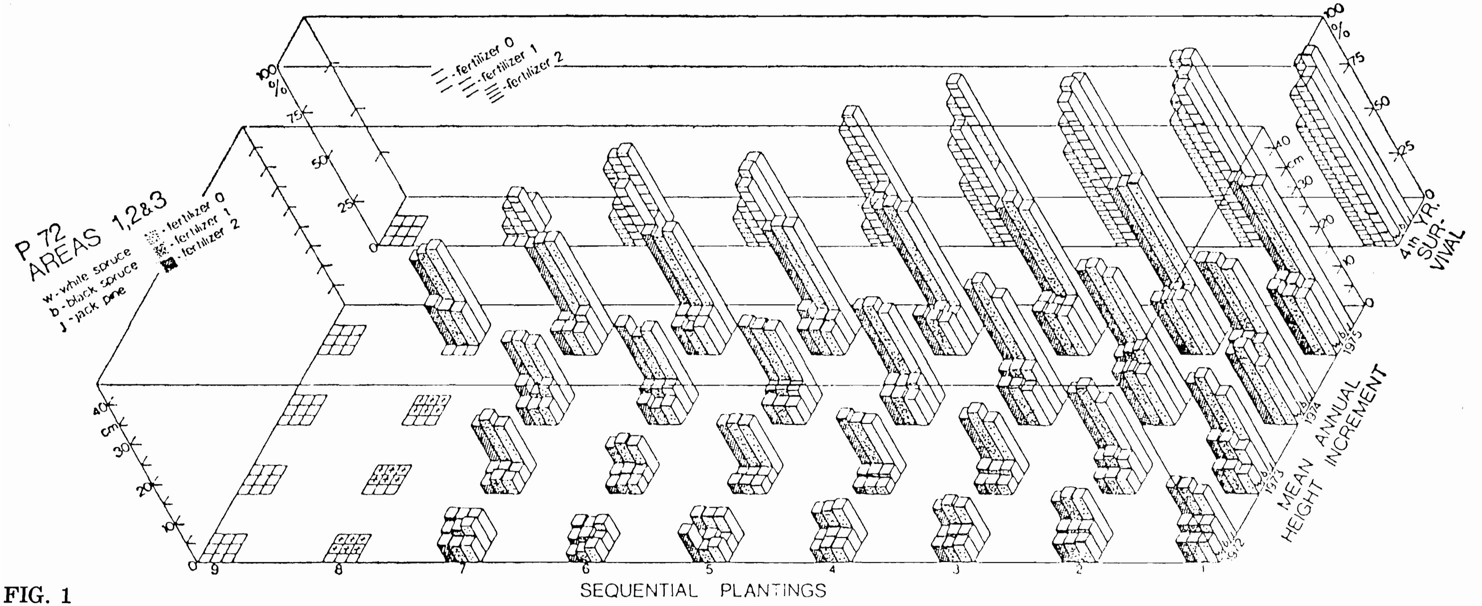

FIG. 1

[redacted]—Field performance of stock sequentially outplanted at 2-weekly intervals in 1972 (P72): mean annual height increment 1972 through 1975 and 4th-year survival, averaged over three sites, by species and fertilizer treatment.

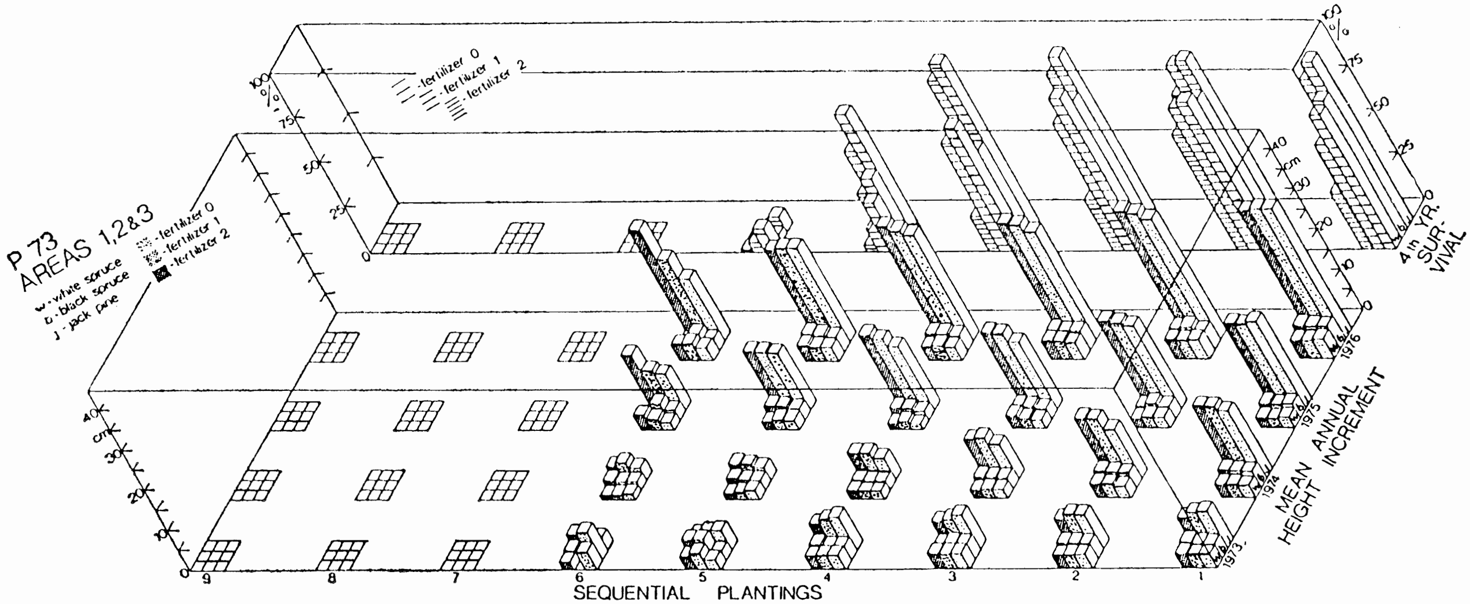

FIG. 2—Field performance of stock sequentially outplanted at 2-weekly intervals in 1973 (P73): mean annual height increment 1973 through 1976 and 4th-year survival, averaged over three sites, by species and fertilizer treatment.

TABLE 10—RGC of jack pine (jP), black spruce (bS), and white spruce (wS) planting stock as estimated by root growth during 21 days in 2 different test environments (growth tank and growth chamber), with related survival and growth performance data for untreated controls, averaged over 3 sites. All stock 4E provenance

			Roots elongated during test period										
			Short roots		Long roots								
		RGC† test no.	(mean number per tree)				Survival after 4 years	Mean annu. ht. increment				Mean total ht. after 4 years	
Year	Species		Tank	Chamber	Tank	Chamber		1st	2nd	3rd	4th		
			(no.)	(no.)	(no.)	(no.)	(%)	(cm)	(cm)	(cm)	(cm)	(cm)	(%)
1972	jP	2	181	– ‡	7.8	–	96.0	12.8	20.2	34.6	38.4	116.7	100
		3	103	124	1.7	4.5	81.5	9.4	13.7	27.4	32.1	88.5	76
		4	65	109	0.9	3.3	63.0	6.8	12.9	18.8	27.8	68.3	59
		5	26	124	0.0	4.2	41.5	6.4	12.2	15.3	24.0	59.0	51
		6	14	0	0.0	0.0	0.0	–	–	–	–	–	–
1973	jP	2	9	265	0.4	24.6	93.3	9.4	17.0	22.1	32.7	88.5	100
		3	32	135	0.4	5.0	97.5	8.4	8.7	17.1	28.3	70.3	79
		4	3	1	0.1	0.0	65.3	4.9	3.2	14.6	23.7	53.0	60
		5	1	0	0.0	0.0	0.0	–	–	–	–	–	–
1972	bS	2	95	–	4.1	–	90.7	7.1	8.8	18.2	14.4	65.6	100
		3	26	42	0.7	0.4	85.2	5.1	3.9	11.5	10.4	42.1	64
		4	65	108	2.1	3.9	25.3	3.0	2.2	6.0	6.6	20.2	31
		5	–	–	–	–	9.5	6.8	3.0	6.8	7.6	25.9	39
		6	35	+ §	0.3	0.0	0.0	–	–	–	–	–	–
1973	bS	2	11	93	1.0	22.9	76.8	3.7	4.4	3.8	5.7	34.3	100
		3	34	49	0.3	2.4	77.7	3.8	2.8	2.5	4.6	29.6	86
		4	6	3	0.0	0.0	34.5	2.1	2.3	2.6	3.9	22.2	65
		5	+	1	+	0.0	0.0	–	–	–	–	–	–
		6	0	0	0.1	0.0	0.0	–	–	–	–	–	–
1972	wS	2	9	–	2.0	–	90.7	5.5	5.3	14.9	14.5	51.7	100
		3	11	8	0.6	0.4	82.3	3.2	2.6	8.8	10.2	35.7	69
		4	10	17	0.2	0.1	24.9	4.1	2.4	4.5	6.0	17.6	34
		5	1	22	0.0	0.4	32.8	4.2	3.4	4.5	5.8	17.3	33
		6	8	+	0.2	0.0	0.0	–	–	–	–	–	–
1973	wS	2	6	14	0.5	1.3	74.8	3.5	3.1	2.6	4.8	23.2	100
		3	5	3	0.0	0.2	85.0	3.9	2.1	2.2	4.4	19.7	85
		4	3	0	+	0.0	26.7	2.5	2.3	2.4	3.6	14.5	62
		5	+	0	0.0	0.0	0.0	–	–	–	–	–	–
		6	1	0	2.8	0.0	0.0	–	–	–	–	–	–

† The first RGC test data are not relevant here because the first sequential outplanting was with planting stock that provided subsamples for the second RRP test.
‡ No data.
§ Trace (<0.5).

TABLE 11—RGC of jack pine (jP), black spruce (bS), and white spruce (wS) as estimated by new root production in 21-day growth tank (T) and growth chamber (C) tests in relation to field performance: correlation with survival, height increment for years 1 through 4 after outplanting (Δh1, Δh2, Δh3, Δh4) and total height after 4 growing seasons in the field, untreated controls, averaged over three sites

	1972						1973					
	jP		bS		wS		jP		bS		wS	
Variable	T	C	T	C	T	C	T	C	T	C	T	C
	Significance of correlations between long roots and:											
Survival	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Height increment year 1	ns	–	ns	–	*	–	ns	ns	ns	ns	*	*
Height increment year 2	**	–	ns	–	ns	–	ns	ns	**	ns	ns	ns
Height increment year 3	ns	ns	ns	–	*	ns	ns	ns	ns	ns	ns	ns
Height increment year 4	ns	ns	ns	–	*	ns	ns	ns	ns	ns	ns	ns
Total height end year 4	*	ns	ns	–	*	ns	ns	ns	ns	ns	ns	ns
	Significance of correlations between short roots and:											
Survival	*	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
Height increment year 1	ns	–	ns	–	ns	–	ns	ns	ns	ns	ns	ns
Height increment year 2	ns	–	ns	–	ns	–	ns	ns	ns	ns	ns	ns
Height increment year 3	*	ns	ns	–	ns	ns	ns	*	ns	ns	ns	ns
Height increment year 4	**	ns	ns	–	ns	ns	ns	ns	ns	ns	ns	ns
Total height end year 4	**	ns	ns	–	ns	ns	ns	ns	ns	ns	ns	ns

third, and fourth year height increments and with total height after four growing seasons in the field.

Otherwise, significant correlations are scattered and without obvious pattern. The basic data certainly suggest that RGC influences survival and growth, but the great variability obscures relationships.

Significant correlations are four times as common among correlations involving growth tank data as with those involving growth chamber data. This is presumed to be due, at least in part, to the greater variability of growth chamber data, as already noted.

In the absence of evidence to the contrary, however, a reasonable thesis seems to be that the greater the RGC (as estimated by root growth in a specified environment during a specified period), the greater will be the ability of such stock to survive and grow well. Admittedly, there may well be threshold values beyond which the amount of new root growth is immaterial. Also, two trees (or two batches of trees) may produce equal amounts of new root growth in unstressful test conditions and yet differ greatly in this regard under stress. Furthermore, even within root types, the sustaining power of two newly elongated roots of the same dimensions cannot be assumed unquestionably to be equal.

CONCLUSIONS

The main conclusions to be drawn from this study are that absolute values given by RGC determinations of the sort described in this paper depend very much on the test environment used, as well as on species, provenance, storage period, and probably type of storage. To be directly comparable, therefore, RGC values must have been obtained by adhering to standardised procedures not only for testing but also for obtaining and handling the sample trees prior to testing. In practical terms, this suggests that a specific and rigidly applied methodology is needed. A system such as developed by Burdett (1979), using semi-quantitative root indexing instead of absolute values and a 1-week test period, would seem to offer important advantages: Burdett's procedure gave results that, for comparative purposes, were largely unaffected by the two very different test temperatures used; and the index of root growth capacity can be presumed to be more representative of the parent stock sampled 1 week earlier than would be justified if longer test periods, commonly 3 or 4 weeks, were used.

The present study provides evidence that both outplant survival percentage and the height increment of surviving trees are correlated with RGC, but, as Burdett (1979) observed, it is by no means clear under what circumstances or to what degree these correlations occur. Precise relationships between RGC and field performance need to be established.

It is clear that if RGC is to be determined with any sort of precision, then the stock whose RGC is estimated from a sample must not be so variable as to cloud the field significance of the RGC values. This implies far greater control over stock rearing procedures than is commonly applied. Räsänen (1972) and Chavasse (1978) advocated the raising of stock under very specific cultural and handling practices, including precision spacing in the nursery, to minimise variation in both size and physiological characteristics.

The strong positive correlation between percentage outplant survival and the height increment of survivors in this study supports a large body of evidence (cf. Ziegler, 1915; Cummings, 1942; Hermann, 1962; 1964, etc.) that suggests the relationship is general. Outplant survival alone, however, would be an insufficient basis for determining RGC-field performance relationships because in many situations, low RGC may depress growth without reducing survival percentage.

In terms of practical silviculture, this study suggests that the regular planting season in boreal Ontario can probably be extended by about 2 months using stored stock before its quality declines to unacceptably low levels.

Finally, the view that RGC is useful in predicting performance, and thus planting stock quality, is reinforced by the fact that significant correlations were found between RGC and field performance, notwithstanding the great variability of the production-run stock used.

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