MONITORING CROP DEVELOPMENT DURING THE REARING OF CONTAINERIZED SEEDLINGS

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Abstract.--Methods of monitoring important growth factors during the production of containerized tree seedlings are discussed. Experience has shown that crop scheduling requires the ability to predict how seedlings will grow. This can be facilitated by setting up a practical program following crop development and by controlling important influences such as soil water, soil fertility and greenhouse climate.

Résumé.--On discute des méthodes de contrôle des principaux facteurs de croissance durant la production des plants en mottes emballées. L'expérience a montré que, pour établir le calendrier des cultures, il faut être capable de prévoir de quelle façon les semis pousseront. On peut y parvenir plus facilement en mettant au point un programme pratique qui permet de suivre la croissance et en contrôlant des facteurs importants comme la teneur en eau et la fertilité du sol ainsi que le climat des serres.

INTRODUCTION

In the Maritimes, the development of greenhouse crops of tree seedlings is usually monitored regularly, by random sampling of seedlings, from each greenhouse. Seedling height and root-collar diameter are measured, and fresh and dry weights of roots and shoots are determined. Often a photocopy is made of a representative seedling on which data are recorded.

Records are also kept of cultural practices such as fertilization, irrigation, or the application of pesticides, and of weather and greenhouse conditions. In addition, the growing medium is routinely analyzed to indicate fertilizer and irrigation needs. Seedling foliage in particular is analyzed when problems arise.

In this paper, methods of monitoring the development of containerized seedlings are discussed. Because crop development and quality depend on effective greenhouse management, methods are also included for monitoring soil water, soil fertility and seedling nutrition.

SAMPLING REQUIREMENTS

To determine sample size, with statistical accuracy, for a practical monitoring program, several crops were evaluated. The variation in seedling height, diameter and dry weight, and the sample size required to estimate means within acceptable limits (± 10%), are given in Table 1 for a crop of white spruce (*Picea glauca* [Moench] Voss) and black spruce (*P. mariana* [Mill.] B.S.P.) raised in FH 408 paperpots.

Sample size and number of samples were determined sequentially according to Day (1979) with the formula:

$$NO = \frac{S^2t^2}{AE^2}$$

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where NO = required number of seedlings
S = standard deviation
t = student's t ($P \leqslant 0.05$)
AE = allowable error (10%)

Three samples are sufficient for estimating total crop means between greenhouses or bays ($P < 0.05$, ±10%). Individual seedling dry weights vary greatly and too large a number of samples is required for this parameter to be a practical statistic. Root-collar diameter appears to be a useful statistical measure, but the measurement is not sufficiently sensitive for estimating required sample size accurately. Succulent seedlings must be measured carefully to avoid damage.

Height is the most practical measure for the statistical evaluation of crop size. It can be measured easily with simple equipment, and seedlings in containers are not damaged. A similar conclusion was reached by McClain (1975) for evaluations of bare-root stock in seedbeds.

If these data are obtained sequentially, unnecessary work is avoided. Day (1979, 1981) and the statistical section in the Ontario Nursery Manual (Armson and Sadreika 1979) are useful references for crop monitoring programs.

STANDARD CURVES AND THEIR INTERPRETATION

The ability to predict crop growth is essential for production planning both in the nursery and in field planting. Standard growth curves can be prepared for different species and conditions (Van Eerden 1974, Scarratt and Reese 1976, Tinus and McDonald 1979, Hallett 1980). For example, standard curves were drawn for height, root collar diameter, and dry weight of several black spruce containerized crops (Fig. 1). These are shown as exponential functions. Many crops produced in the Maritimes were outplanted in the year of production while still actively growing. Therefore, the upper curve values varied with the time of planting and total seedling dry weights ranged from a suggested minimum of 650 to 2,020 mg.

Curves for winter and summer crops show differences in growth equivalent to two months of growing time. Comparison with such standard curves can be used to determine if growth is on schedule to meet production or field planting dates, or to evaluate the success of cultural practices.

Regression equations for these exponential growth curves were calculated. Useful correlations exist between seedling dry weight and height and diameter (e.g., the

Table 1. Mean seedling heights, root-collar diameters, and total seedling dry weights with standard errors (SE), and required sample sizes with 10% allowable error at the 95% level of probability (Greenhouse N = 180; All N = 720)[a]

		Height		Root-collar diameter		Total seedling dry weight	
Species	Greenhouse	Mean ± SE (cm)	Required sample size	Mean ± SE (mm)	Required sample size	Mean ± SE (mg)	Required sample size
White spruce	9	10.3 ± 2.7	26	1.5 ± 0.3	16	378 ± 181	89
	10	11.6 ± 2.7	21	1.6 ± 0.3	16	465 ± 204	74
	11	10.9 ± 2.4	20	1.5 ± 0.3	17	406 ± 180	76
	12	10.8 ± 2.2	17	1.5 ± 0.3	16	398 ± 177	77
	All	10.9 ± 2.5	15	1.5 ± 0.3	16	412 ± 188	81
Black spruce	13	15.9 ± 3.5	20	1.5 ± 0.3	18	441 ± 203	82
	14	12.9 ± 2.9	21	1.4 ± 0.3	19	322 ± 147	81
	15	15.1 ± 2.6	12	1.6 ± 0.3	14	429 ± 171	61
	16	12.5 ± 2.6	16	1.4 ± 0.3	12	341 ± 155	79
	All	14.1 ± 3.3	21	1.5 ± 0.3	18	383 ± 178	83

[a] Data collected by S.I. Cameron and R.D. Hallett, Maritimes Forest Research Centre.

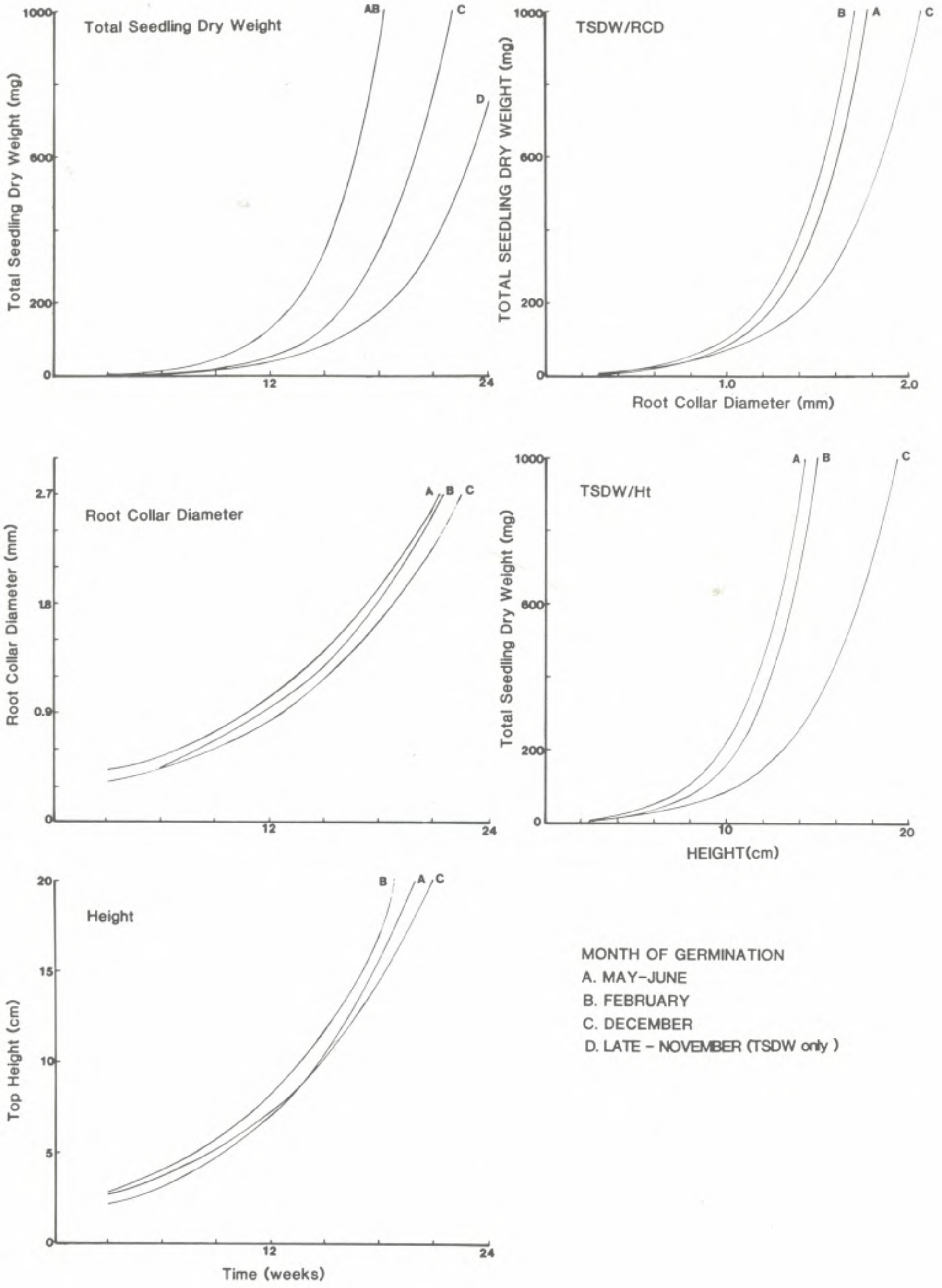

Figure 1. Standard curves showing seasonal patterns of growth of containerized black spruce seedlings raised in greenhouses.

equation for February dry weight vs height: $Y = 4.43e^{0.04x}$, r2 = 0.88 where Y = dry weight, x = height). For convenient non-destructive sampling this relationship can be used to estimate dry weights from height (Armson and Sadreika 1979, Day 1979).

ROOT GROWTH

Root development is often ignored until it is time to ship the seedlings, when the plug or paperpot must be extractable and plantable. Root weights are commonly measured: what use can be made of the data? Shoot:root ratios may help to detect inferior root development. For example, with winter crops raised under poor natural light, greenhouse temperatures, soil moisture and nutrients must be managed carefully to prevent spindly shoots and weak root development.

Carlson (1979) states that, at shipping, the dry weight of roots per cm^3 of rooting volume should be greater than 4.0 mg; consequently, root dry weight may also be used to assess extractability of the plug. The root area index used in Ontario nurseries (Armson and Sadreika 1979) could also be used to assess quality.

MONITORING GREENHOUSE ENVIRONMENT

In the container nursery, the opportunity to maximize growth lies in the ability to control environmental factors. Often, differences in growth may be due simply to climatic factors. While the greenhouse climate may be sensed by those passing through and temperature and relative humidity are recorded by gauges, variation can be considerable. The use of hygrothermograph and weather data is most helpful in answering questions if growth is not as expected.

The nurseryman's greatest influence on crop development is usually through the use of water and fertilizers, although he may not have adequate knowledge of what is happening.

MONITORING SOIL WATER

Poor irrigation practices frequently cause trouble in the greenhouse. Water applications may be too heavy, too light, too often, too infrequent or too uneven, but whatever the problem, seedlings do not grow as well as they should.

Several methods are used to monitor soil water. The simplest is to weigh the containers. However, the seedling's need for water or the degree of moisture stress can be assessed through use of the pressure bomb (Carlson 1979, McDonald and Running 1979, Day 1980). (For a detailed description of the use of the pressure bomb see Day and Walsh 1980.)

Weight of Containers

Differences in soil moisture levels can be detected by weighing flats of seedlings. Several flats from various areas of the greenhouse should be marked for weighing because the weights may vary greatly on account of their proximity to heating or cooling equipment, walks, etc. Enough weights are needed to give a reliable assessment.

Growth of each species and in each type of container should be studied to determine optimal soil moisture levels, but first a safe approximation is needed for the commercial grower. McDonald and Running (1979) suggested that containers be allowed to dry to 75-80% of their saturated weight, then be rewatered to drip (near field capacity).

The reaction to different levels of soil water and fertility varies with species (Table 2). From studies such as these, a range in weight of 13.5 to 14.5 kg is suggested for FH 408 paperpot flats and the minimum weight for styroblock-4s and styroblock-8s is 5.8 kg (Table 3).

Day (1980) concludes that "the secret of effective nursery irrigation is to keep the interstices of the soil filled with both water at low matric potential (i.e. -0.1 to -0.5 Bar tension) *and* air in order to minimize plant water stress." Day (ibid.) and McDonald and Running (1979) prescribe soil moisture retention curves which show the relationship between the amount of water in the soil and the tension at which it is held. Puustjrvi et al. (1972) similarly developed moisture release curves for different grades

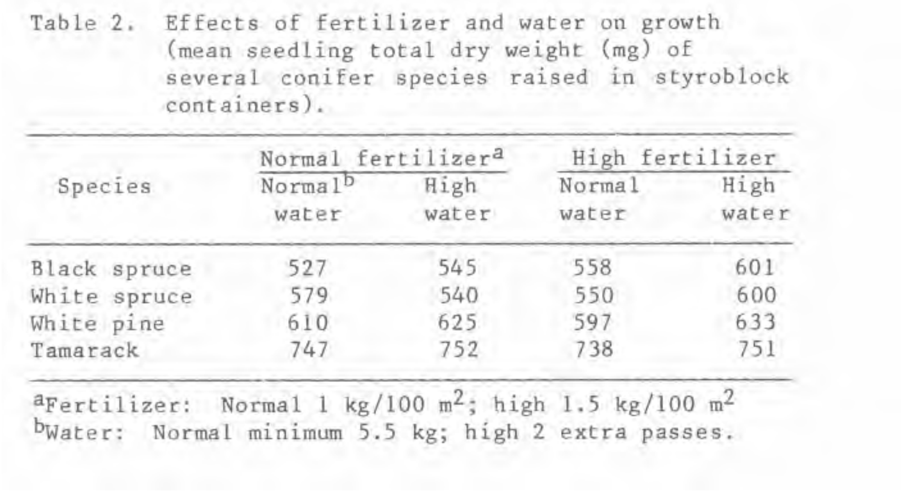

Table 2. Effects of fertilizer and water on growth (mean seedling total dry weight (mg) of several conifer species raised in styroblock containers).

Species	Normal fertilizer[a]		High fertilizer	
	Normal[b] water	High water	Normal water	High water
Black spruce	527	545	558	601
White spruce	579	540	550	600
White pine	610	625	597	633
Tamarack	747	752	738	751

[a] Fertilizer: Normal 1 kg/100 m^2; high 1.5 kg/100 m^2

[b] Water: Normal minimum 5.5 kg; high 2 extra passes.

Table 3. Recommended container weights and total soil moisture content (T.S.M.C.) by weight and by volume.

Container	Recommended weight (kg)	Weight of medium[a] in containers		Water weight (kg)	Total medium volume (L)	Pore vol of medium (%)	Weight pore vol filled water (kg)	T.S.M.C. by	
		Wet (kg)	Dry (kg)					wt (%)	vol (%)
Paperpot FH 408	13.5-14.5	11.5-12.5	1.50	10-11	24	96	23	660-730	43-48
Styroblock 4	min. 5.8	5.8	0.54	3.46	9.6	94	9.2	640	38

[a] Growing medium was peat in paperpots and peat plus vermiculite in styroblocks.

of peat (Fig. 2). Their optimal soil moisture range for a medium coarse peat was 42.5 to 46.1% by volume with an associated air capacity of 53.6 to 50%, and soil moisture tension less than -0.55 Bar (close to Day's [1980] recommendation). The soil water content at recommended container weights for local data is comparable (Table 3).

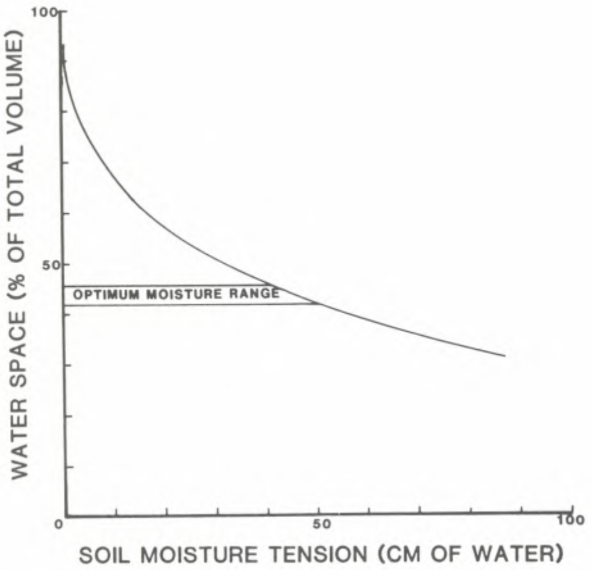

Figure 2. Soil water characteristic curve for medium coarse peat showing optimum moisture range (100 cm = 0.1 Bar). Adapted from Puustjarvi et al. (1972).

SOIL FERTILITY

Often, little is known about the level of soil fertility and how it changes with fertilization and irrigation. Several methods are used to fertilize containers: a once-weekly "shot" of concentrated fertilizer solution followed by irrigation; a once-weekly "soak" with a less concentrated fertilizer; "constant" application of a fertilizer of very low concentration with every irrigation; and "slow-release" fertilizers mixed in the medium at the start of production.

Nutrients are readily leached from peat or peat-vermiculite growing media, yet root and shoot injury from excessive concentrations of total salts or individual elements is still possible because of rapid changes in soil moisture. Management of the greenhouse soil and water is usually very intensive and changes can take place quickly. Frequent testing of soils for nutrient content is recommended.

Analysis of greenhouse soils

Soil test kits were developed in horticulture for rapid determination of pH, soluble salts, and the macroelements. Use of the kits and the interpretation of results requires experience and can take a lot of time. However, in most regions greenhouse soil testing is done as a service at various soil and plant testing laboratories. Fast service is needed for intensively fertilized greenhouse soils. Over five years, greenhouse managers in the Maritimes have submitted more than 4,000 samples for testing. Results have been monitored and an interpretation scheme developed for containerized tree seedling production (Table 4). The grower must become familiar with the results from the laboratory he uses because of variation in testing techniques (Hanan et al. 1978).

Table 4. Recommended greenhouse ranges of nutrients in peat and peat-vermiculite growing media fertilized with soluble fertilizers.

Salts mhos x 10^{-5}	pH	Available nutrients in ppm in soil extract[a] N	P	K	Ca	Mg
Horticultural crops						
30	6.2	6	6	20	min	min
120	7.2	12	16	59	150	6
Tree seedlings						
25	4.0	6	8	15	min	min
50	6.0	12	16	30	5	3

[a] Specific recommendations are available for different stages of seedling development.

Samples must be collected and handled carefully for reliable results. Growers randomly select several locations in the greenhouse at which they collect a soil plug, remove the surface grit and soil, then combine the medium to make one sample. Self-addressed, wax-lined cardboard boxes or plastic-lined bags are provided by the laboratory for shipping.

At the Maritimes Forest Research Centre laboratory, the soil is mixed and a fixed volume is sub-sampled. Because the samples are not dried before analysis, they should not be shipped dry one week and saturated the next. Samples should be taken after the medium is irrigated or fertilized, and allowed to drain to field capacity. High readings result if the samples are delayed in the mail or collected a long time before analysis.

Greenhouse soil analysis is an effective tool for greenhouse managers, not only for those using periodic additions of soluble fertilizers but also for constant fertilization or for soils amended with slow-release fertilizers. Figure 3 shows the initial reduction in excessive fertility and the week-to-week variation in nutrient content at a nursery using weekly fertilization. Analyses from greenhouses using constant fertilization are less variable but are still required, particularly during phases of production when changes are required, such as hardening-off, or for crops grown outside when rainfall may cause considerable nutrient losses.

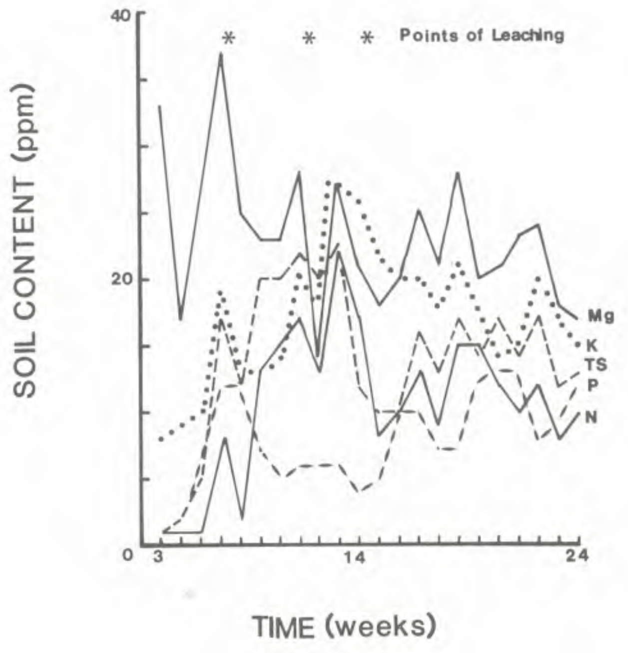

Figure 3. Trends in total salts (TS), nitrate nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) as determined weekly by laboratory analysis for a containerized black spruce crop raised in the greenhouse in a peat-vermiculite growing medium (December-May).

FOLIAR ANALYSIS

Soil analysis data can be used to compare concentrations of soil nutrients with predetermined levels of fertility. Seedlings should also be analyzed periodically for nutrient content to measure the response to the levels of fertility provided and to relate this to the growth achieved. The ranges in nutrient concentrations in the foliage of bare-root nursery stock in Ontario are presented by Armson and Sadreika (1979). Such published information is not yet available for container stock, although several sources give values or suggestions for interpretation (Brix and van den Driessche 1974, Owston 1974, Tinus 1974, Tinus and McDonald 1979).

Foliar analysis data are difficult to interpret. To follow the advice of Tinus and McDonald (1979), the nurseryman can collect data at different stages of development of a satisfactory crop and use them for future comparisons.

Nitrogen concentrations

Probably the simplest way to use foliar analysis data would be to look first at the actual concentration of nitrogen and determine if it is adequate, deficient, or excessive. Guidelines for nitrogen content are given in Table 5 for local spruce and pine *(Pinus* spp.) at different stages of development.

Ingestad nutrient proportions

The second step in the evaluation of seedling nutrient concentration data would be to calculate the "Ingestad" nutrient proportions rather than attempting to evaluate the concentrations of the other elements in the foliage. These are the proportions of the other elements in relation to nitrogen (e.g., P/N x 100). Ingestad (1962, 1967) stated that "the proportions of elements in plants at optimum nutrition vary insignificantly with species or age of plant, although the absolute concentrations and quantities may vary." He considered the following nutrient proportions to be optimal: nitrogen 100; phosphorus 13; potassium 65; calcium 6; magnesium 8.5; sulfur 9; iron 0.7; manganese 0.4; boron 0.2; copper 0.03; zinc 0.03; chlorine 0.03 and molybdenum 0.003. In the Maritimes, macronutrients have been used successfully in the following proportions (nitrogen = 100); phosphorus 10 to 13; potassium 40 to 65; calcium minimum 6; and magnesium minimum 6. By using these proportions and the suggested nitrogen concentrations, one can readily assess the relative nutrient content of a sample. Foliar analysis data for several good crops of containerized black spruce are presented in Table 6.

USE OF MONITORING DATA

The use of monitoring data is illustrated in Table 7, where differences in total seedling dry weight, shoot:root ratio, soil nitrogen, and foliage nutrient concentrations are related to seasonal, fertilizer, or supplementary lighting treatments of black spruce crops.

Predicting growth reliably depends on the establishment of a good data base which includes seedling development, soil water and fertility and seedling nutrient content. By the use of such data, problems can be better assessed with confidence since it is soil water and fertility, combined with greenhouse climate and weather conditions, that determine the growth of a crop.

Table 5. Provisional guidelines for nitrogen concentration (%) in containerized seedlings at various ages and stages of development.

	Age (weeks)			
Species	3 - 10	10 - 16	Hardening	Overwintering
Spruce	2.8 - 3.0	2.5 - 2.8	2.2 - 2.5	1.9 - 2.2
Pine	3.2 - 3.6	2.5 - 3.0	2.5 - 2.8	1.9 - 2.2

Table 6. Foliage nutrient concentrations (% or ppm) and macronutrient proportions from satisfactory crops of containerized black spruce seedlings.

Age (weeks)	Nutrient concentrations										Nutrient proportions			
	N	P	K	Ca	Mg	B	Fe	Mn	Cu	Zn	P	K	Ca	Mg
	(%)					(ppm)					(Nitrogen = 100)			
10-14	2.73	0.44	1.39	0.23	0.16	28	99	306	15	47	16	51	8	6
15-18	2.44	0.38	1.34	0.24	0.17	89	68	200	9	33	16	55	10	7
19-26	2.50	0.36	1.15	0.37	0.22	37	127	107	16	45	14	46	15	9

Table 7. Dry weights and shoot:root ratios of containerized black spruce seedlings raised in peat or peat and vermiculite in winter and summer under different fertility or lighting regimes, with associated foliage nutrient concentrations and proportions.

	Month seeded	Treatment	Age (wk)	Total seedling dry weight (mg)	Shoot: root ratio	Soil nitrate nitrogen (ppm)	Foliage nitrogen content (%)	Ingestad nutrient proportions (Nitrogen = 100) P	K	Ca	Mg	Comments
A.	Sept.	High nitrogen fertilizer	13	86	6.8	25	2.94	13	55	10	6	Excessive nitrogen, slow growth rate.
B.	Sept.	As in A but with HID lighting	13	699	5.8	7	1.74	15	61	11	6	Fast growth rate resulting in nitrogen deficiency.
C.	Nov.	High fertility	16	150	6.5	32	2.84	17	46	9	7	Excessive nutrients with seedling losses.
D.	Nov.	As in C but with modified fertility	16	200	3.4	7	2.51	14	56		6	Better growth without injury.
E.	Jan.	Reduced fertilizer levels	11	44	4.5	2	2.16	23	59	9	9	Slow growth and nitrogen deficiency.
F.	Jan.	Recommended fertilizer levels	16	585	5.5	10	2.65	14	42	6	6	Good growth.
G.	June	"Normal" rate 28-14-14	13	175	4.3	2	2.75	14	33	9	6	Acceptable growth.
H.	June	Increased rate 28-14-14	13	290	6.6	3	3.04	11	36	7	6	Better growth.
I.	June	Excessive rate 28-14-14	13	255	10.0	12	3.41	11	31	3	4	Inferior growth.

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