AN EVALUATION OF SOME COMMERCIAL SOLUBLE FERTILIZERS FOR CULTURE OF JACK PINE CONTAINER STOCK

J.B. SCARRATT

GREAT LAKES FORESTRY CENTRE

CANADIAN FORESTRY SERVICE

GOVERNMENT OF CANADA

1986

INFORMATION REPORT 0-X-377

Catalogue No. Fo46-14/377E
ISBN 0-662-15004-X
ISSN 0832-7122

Additional copies of this publication are available at no charge from:

Communications Services
Great Lakes Forestry Centre
Canadian Forestry Service
Government of Canada
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

ABSTRACT

Commercial soluble fertilizers specifically formulated for use in the greenhouse culture of containerized coniferous seedlings have been recently introduced. Growth and foliar nutrient uptake in jack pine paperpot seedlings fertilized with these "forestry" formulations were compared with those of seedlings fertilized with some of the more commonly used general-purpose horticultural formulations. There were no significant differences in growth response or seedling ontogeny between fertilizer treatments. From an operational viewpoint, the "forestry" fertilizers proved no better and no worse than general-purpose fertilizers in the summer production of 12-week-old container stock. The similarity of foliar nutrient uptake indicates that all treatments provided an adequate, if not abundant, supply of macro- and micronutrients. The results provide no evidence to indicate that special "starter", "grower" and "finisher" formulations are necessary in the production of jack pine under optimum growing conditions.

RÉSUMÉ

Des engrais solubles commerciaux conçus spécialement pour la culture en serre de semis de conifères en récipients ont été lancés sur le marché récemment. Cette étude compare, chez des semis de pin gris cultivés en récipients de papier, l'accroissement et l'assimilation foliaire des substances nutritives obtenus avec des préparations "pour usage forestier" et avec des préparations horticoles pour usage général, parmi les plus couramment utilisées. Aucune différence significative n'a été observée entre les traitements pour l'accroissement et l'ontogenèse des semis. Du point de vue opérationnel, les engrais pour usage forestier ne se sont révélés ni meilleurs ni pires que les engrais pour usage général en ce qui concerne la production estivale de semis en récipients de 12 semaines. La similarité de l'assimilation foliaire des substances nutritives indique que tous les traitements ont assuré un approvisionnement adéquat, sinon abondant, en macro-éléments et micro-éléments. Les résultats n'indiquent pas que des préparations spéciales de démarrage, de croissance et de finition sont nécessaires pour la production du pin gris dans les conditions optimales de croissance.

ACKNOWLEDGMENTS

The author is indebted to W.R. Grace & Co., Peters®/Terra-Lite® Testing Laboratory for conducting the chemical analyses described in this report.

TABLE OF CONTENTS

INTRODUCTION

The soilless growing media used in the culture of containerized tree seedlings, while having desirable physical properties, generally provide little by way of available mineral nutrients (Bunt 1976, Whitcomb 1984). While the vermiculite in peat-lite mixes (Boodley and Sheldrake 1982) contains sufficient K and Mg to supply most plants (Tinus and McDonald 1979), for the most part the nutrients required for normal seedling growth and development must be supplied through supplemental fertilization. Of available methods, the incorporation of granular fertilizers into the growing medium is least desirable for a number of reasons (Tinus and McDonald 1979), and has been largely abandoned as a primary means of supplying nutrients to soilless mixes. Most container operations in eastern Canada now use soluble fertilizers, applied frequently and at low concentrations through the irrigation water[1].

Users of soluble fertilizers may elect either to purchase a "complete" commercial formulation containing macro- and microelements or to mix their own from technical grade chemicals. While the latter is appealing because of the theoretical ability to tailor nutrition to a specific crop situation, few operational container nurseries have either the resources or the expertise required to formulate and prepare their own fertilizer blends (cf. Tinus and McDonald 1979). Consequently, most container growers find it simpler and more convenient to use commercial premixed soluble fertilizers in their operations.

Notwithstanding the restrictions imposed by use of commercial fertilizers, the selection and development of fertilizer regimes for container stock has been molded by the general perception that nutritional needs change with stage of seedling development (Brix and van den Driessche 1974, Tinus and McDonald 1979). This has given rise to the widespread practice of using different rates and/or fertilizer formulations for different phases of the production cycle (e.g., Edwards and Huber 1982, Hallett 1982a, Matthews 1982). Thus, a "starter" fertilizer (low N, high P, moderate K) is commonly used, at low concentrations, during the juvenile phase while seedlings are becoming established. This is followed by a "grower" formulation (high N or a balanced fertilizer) at a higher concentration during the exponential growth phase. Finally, a "finisher" (low N, moderate-to-high P, moderate-to-high K) may be used during the hardening and conditioning phase, perhaps increasing N after budset. Although fertilizer rates and formulations may vary widely from operation to operation, most container nurseries use variants of this basic regimen.

Until fairly recently, container growers who wanted the convenience of ready-to-use commercial fertilizers had to choose from formulations developed primarily for horticultural crops. Although many successful crops of tree seedlings have been produced with these horticultural fertilizers, the recent introduction of commercial soluble fertilizers specifically intended for use in the

---

[1]In British Columbia a significant proportion of seedlings are raised in growing media amended with slow-release fertilizers, supplemented by soluble fertilizers during the growing season (J.T. Arnott, Pacific Forestry Centre, Canadian Forestry Service, Victoria, B.C. - personal communication. See also Matthews 1982).

culture of coniferous tree seedlings was greeted with enthusiasm. However, as will be discussed later, aside from supplemented microelement levels these new "forestry" fertilizers have, within broad limits, NPK levels somewhat similar to those of the horticultural formulations already used in conifer production in eastern Canada.

The present experiment was initiated primarily to determine whether, in the greenhouse culture of jack pine (*Pinus banksiana* Lamb.) paperpot seedlings, the results obtained with the special "forestry" formulations were any different from those obtained with the more commonly used horticultural formulations. Different manufacturers' products were included, and all treatments included a starter, a grower and a finisher. With one exception, constant fertilization was used for all treatments. Application rates, adjusted to similar N levels, were based upon regimes recommended by the author for growing coniferous container stock in Ontario. These are somewhat on the conservative side, perhaps, but experience has shown them to be adequate under most circumstances.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse at the Great Lakes Forestry Centre in Sault Ste. Marie. Trays of FH408 Japanese paperpots (3.8 cm diam. x 7.5 cm deep; 336 pots/tray @ 1066/m^2) were filled with a 2:1 peat moss:horticultural grade vermiculite mixture on a stationary vibration table. Jack pine seeds were sown on 22 June, covered with a thin layer of #10 silica grit, and the paperpot trays were transferred to greenhouse benches (32°/20°C day maximum/night minimum; 18-hour photoperiod[2]). During germination and prior to the start of fertilizer applications, seedlings were irrigated as required with city water.

Germination started on 28 June and was completed by 6 July. For computation purposes, 4 July was adopted as the effective germination date; all subsequent references are based on this date.

Seedlings were thinned to one per cavity at the cotyledon stage. Fertilizer treatments began on 8 July, as soon as primary needle development became evident. Treatments were arranged in a randomized block design with five replications, each treatment replicate comprising a single paperpot tray.

Fertilizer Treatments

Ten nutrient regimes were compared, all but one using commercially available, "complete" water-soluble fertilizers. The exception, a prescription nutrient solution published by Hocking (1971, 1972), was included because, having been developed specifically for the culture of coniferous seedlings, it offered a convenient standard by which to judge the commercial formulations.

---

[2]Daylength extension with 1000 watt General Electric Multi-Vapor/O HID lamps providing 7600 lux at plant level.

All nutrient regimes comprised a starter (3 weeks' duration), a grower (7 weeks' duration), and a finisher (1 week's duration). Among the commercial fertilizers, various options were tested. Treatments 2 and 4 (Table 1) used Plant Products and Peters® general-purpose 20-20-20 fertilizers throughout, only the application rates being changed for the different growth phases. These regimes are frequently used for growing jack pine, the difference between the two manufacturers' products being principally one of microelement analysis (Appendix I). Treatment 5, a 20-19-18 formulation manufactured by Peters® specifically for peat-lite growing media, and containing supplementary trace elements, was included as a potential alternative to the general-purpose formulations. Treatments 6 and 8, using Plant Prod and Peters® fertilizers, respectively, represent the most common nutrient regimes used for container culture in Ontario. A high P formulation, at a relatively low rate, was used as a starter and finisher, with a balanced high N grower during the exponential growth phase. Aside from the differences in P and K levels, the principal differences between the two manufacturers were in microelement levels.

The above treatments using horticultural fertilizers were contrasted with the new "forestry" formulations (treatments 7 and 9, respectively). In all of the above, the finisher rate was rather conservative (25 ppmN); treatment 10 was therefore included to evaluate the effect of a higher rate (50 ppmN) for one of the special "forestry" finishers.

While a constant fertilization program was adopted for all other treatments, treatment 3 was fertilized only intermittently and at an accordingly higher rate. Such a regime is preferred by a few growers and its inclusion in this experiment, with a typical 20-20-20 formulation used throughout, was intended to provide an example for comparison of this alternative approach.

Published analyses for the 11 commercial fertilizers used in the experiment are given in Appendix I. Elemental nutrient concentrations calculated for the various treatments are listed in Appendix II.

With the exception of treatment 3 (intermittent fertilization), seedlings were watered by hand with 3 L of nutrient solution per tray roughly every other day, care being taken to maintain a slight leaching action through the growing medium. More frequent applications were often necessary as the seedlings grew larger.

All constantly fertilized treatments received the same number of nutrient applications in the same volumes of water, as follows:

	Period	No. of applications
Starter	8 July - 28 July	10
Grower	30 July - 15 Sept.	20
Finisher	17 Sept. - 23 Sept.	5

Table 1. Summary of fertilizer treatments[a]

Treatment number	Fertilizer make[b]	Description	Fertilization stage, formulation and application rate (ppm N)		
			Starter	Grower	Finisher
1	Hocking	Prescription	Half rate (56)	Full rate (112)	Half rate (56)
2	Pl. Prod.	General purpose	20-20-20 (50)	20-20-20 (100)	20-20-20 (25)
3[c]	Pl. Prod.	General purpose	20-20-20 (150)	20-20-20 (300)	20-20-20 (75)
4	Peters	General purpose	20-20-20 (50)	20-20-20 (100)	20-20-20 (25)
5	Peters	Peat-lite special	20-19-18 (50)	20-20-20 (100)	20-20-20 (25)
6	Pl. Prod.	High-P starter	10-52-10 (50)	20-20-20 (100)	10-52-10 (25)
7	Pl. Prod.	Conifer special	11-41-8 (50)	20-8-20 (100)	8-20-30 (25)
8	Peters	High-P starter	9-45-15 (50)	20-19-18 (100)	9-45-15 (25)
9	Peters	Conifer special	7-40-17 (50)	20-7-19 (100)	4-25-35 (25)
10	Pl. Prod.	Conifer special	11-41-8 (50)	20-8-20 (100)	8-20-30 (50)

[a]More detailed descriptions of the fertilizers used, including trace element analyses, are given in Appendix I

[b]Pl. Prod. = Plant-Prod Water Soluble Fertilizers manufactured by Plant Products Co. Ltd., Bramalea, Ontario; Peters = Peters® Soluble Fertilizers supplied by W.R. Grace & Co. of Canada Ltd., Ajax, Ontario

[c]This treatment operated on an intermittent rather than a constant fertilization program

In the intermittent fertilization treatment (treatment 3) nutrients were applied on Tuesdays and Fridays only (starter - 5 applications; grower - 14 applications; finisher - 3 applications). Clear tap water was applied as necessary on intervening days, generally at the same times and rates as were used in applying nutrients to other treatments, and in sufficient quantities to ensure a slight leaching action. All treatments were thoroughly leached with clear water prior to each change in fertilizer regime.

Sampling

Growing media samples were taken for analysis before the start of fertilizer treatments and, for each treatment, just prior to leaching at each change of fertilizer regime (i.e., starter/grower, grower/finisher). Two random containers were taken from each treatment replicate, the silica grit and seedling roots were removed, and the material was bulked, mixed and air-dried.

Samples for tissue analyses were taken (two random seedling shoots per replicate) at 6, 10 and 12 weeks from germination. Seedling shoots were bulked for each treatment and oven-dried for 48 hours at 70°C.

Tissue and growing medium analyses, as well as a water analysis, were carried out by the Peters®/Terra-Lite® Testing Laboratory in Fogelsville, Penn. (W.R. Grace & Co.), utilizing an Inductively Coupled Argon Plasma Spectrometer (ICAP) and Antek Nitrogen Analyzer (Shadan and Peters 1981). Extraction was by dry ashing/nitric acid digestion and saturated paste method for tissue and growing medium analyses, respectively.

Sampling for seedling measurement began 2 weeks after germination and was repeated at 2-week intervals until week 12. Five seedlings were sampled at random from each treatment replicate, edge trees being avoided. Depending on stage of seedling development, measurements included shoot height, root-collar diameter, shoot and root dry weights, and root area index (Morrison and Armson 1968). Growth data were compared by one-way analysis of variance, and differences between means were evaluated by Tukey's w-procedure where appropriate.

RESULTS AND DISCUSSION

The presentation of results is divided into three sections, *viz.*, nutrient supply, seedling growth response, and foliar analysis.

Nutrient Supply

Application rates of N were held more or less constant during each cultural phase (i.e., starter, grower, finisher), although the sources of N differed considerably within the starter and finisher formulations (Appendix I). With the exception of the Peters® Conifer Grower (treatment 9), N-source proportions were similar in the grower formulations (approx. 53% urea, 20% NH_4, 27% NO_3).

While seedlings received similar amounts of N they were exposed to substantially different levels of the other macronutrients (Table 2 and Appendix II). The highest P rates occurred with the starter and finisher formulations of treatments 6 to 10, which included the "forestry" fertilizers. But the "forestry" fertilizers (treatments 7, 9, 10) also had the lowest P concentrations during the grower phase, averaging only 40% of those in the other commercial fertilizers. Potassium levels were fairly similar across treatments during the grower phase (except for treatment 1 - high), but were substantially higher in the "forestry" fertilizers during the finisher phase. Small amounts of K will have been contributed by the vermiculite in the growing medium (Tinus and McDonald 1979).

Table 2. Minimum and maximum macronutrient application rates (ppm)[a]

Element	Starter	Grower	Finisher
N	50 - 56	100 - 112	25 - 56
P	15.5 - 124.7	15.2 - 43.6	10.4 - 68.2
K	30.2 - 100.8	74.7 - 156.0	18.7 - 181.8

[a] Excludes treatment 3; see Appendix II for details of specific treatments.

It is useful to compare macronutrient proportions (N = 100) in the fertilizers used during the exponential growth phase with those recommended by Ingestad (1962, 1967, 1979) for maximizing growth of Scots pine *(Pinus silvestris* L.) seedlings *(viz.,* P 13; K 65; Ca 6; Mg 8.5). Similar N:P:K proportions (P 12; K 69) were successfully used by Tinus (Tinus and McDonald 1979, Table 13-13) to grow western conifers. On the basis of these standards, all grower formulations used here had relatively high K proportions (Table 2). Phosphorus proportions conformed reasonably well in the "forestry" fertilizers (15.2 - 17.5), but were between 2.4 and 3.3 times higher than Ingestad's values in the other treatments. This suggests that all commercial fertilizer treatments supplied adequate to abundant P and K during the grower phase.

In strong contrast to the Hocking solution (treatment 1), where the proportions far exceeded Ingestad's recommendations, none of the commercial fertilizers contained any Ca or very high levels of Mg. The Plant Products general-purpose fertilizers (treatments 2, 3, 4, 6) contained neither Ca nor Mg and, even in those fertilizers which did supply Mg, levels were usually less than 1 ppm. Only in the Peters® "forestry" formulations did Mg levels exceed 1 ppm (but still < 2% at N = 100 in the grower fertilizers, in comparison with Ingestad's figure of 8.5). No attempt was made to supplement Ca and Mg levels since the irrigation water contributed fairly significant amounts of both elements (40 and 6 ppm, respectively - Appendix III).

An adequate supply of trace elements is essential for normal seedling nutrition and development (Bunt 1976, Puustjarvi 1977). Within this experiment, trace element levels varied considerably from treatment to treatment. Again, it is useful to compare application rates in the various treatments (Appendix II) with the proportions cited by Ingestad (1967) *(viz.,* Fe 0.7; Mn 0.4; B 0.2; Cu

0.03; Zn 0.03; Mo 0.007). Micronutrient levels were lowest in the general-purpose fertilizers, these having been originally formulated for use with growing media containing mineral soil. When these fertilizers are used with soilless media, which are frequently deficient in micronutrients (Bunt 1976), it may be necessary to supplement trace element levels. Supplemental trace elements were deliberately not added in this experiment in order to determine whether seedling growth might be adversely affected.

By way of contrast, the new "forestry" fertilizers are specifically intended for use with soilless growing media and, to meet the perceived needs of coniferous seedlings, both manufacturers have produced formulations with substantially increased levels of trace elements (even higher than in the Peters® Peat-Lite® Special), particularly of Fe. Proportions of Fe, Cu and Zn are several times higher than those recommended by Ingestad (1967). (Compare values in Appendix II with Ingestad's above.)

Results of the water and pre-treatment growing medium analyses, summarized in Appendix III, were within acceptable limits. Water quality was good, although pH was high. However, Sault Ste. Marie city water typically has a pH in the range of 8.0 - 8.4 and, while the addition of fertilizers reduced the pH of the irrigation water to just below neutral, the pH of the growing medium remained fairly constant (4.0 - 4.4) in all treatments over the course of the experiment.

Levels of major elements in the growing medium are depicted in Figure 1. As might be expected, results of the early analyses were generally proportional to the composition of the fertilizer being applied. (Note that date A represents the end of the starter phase, date B is after leaching, and date C is after six applications of grower fertilizer.) However, while nutrient levels continued to reflect some of the more pronounced differences between fertilizer regimes, the overall relationship between elemental application rates and levels in the growing medium generally became much weaker by the end of the grower phase (i.e., date D, after 20 applications of grower solution). This can be attributed to differential rates of nutrient utilization and accumulation in the various treatments.

Nutrient levels in the growing medium at the end of the grower phase are given in detail in Appendix IV. None of the values was especially high by horticultural standards (unpublished ranges of W.R. Grace & Co.). As expected, the highest N, P, and K concentrations were generally found in treatment 3, on the intermittent feed program (Fig. 1). Treatment 1 (Hocking solution) also had higher-than-average levels of most elements except P and Fe although, in contrast with treatment 3, these high levels were accompanied by a marked elevation of salt levels throughout the grower phase. Comparison of growing media analyses with elemental application rates (Appendix II) indicates a fairly substantial accumulation of Ca and Mg in treatment 1, as illustrated in Figure 1. Surprisingly, there was also some accumulation of Ca and Mg in treatments 2-10. This suggests that the concentration of these elements in the irrigation water (Appendix III) was sufficient to satisfy seedling requirements, and that the levels provided by the Hocking solution were unnecessarily high.

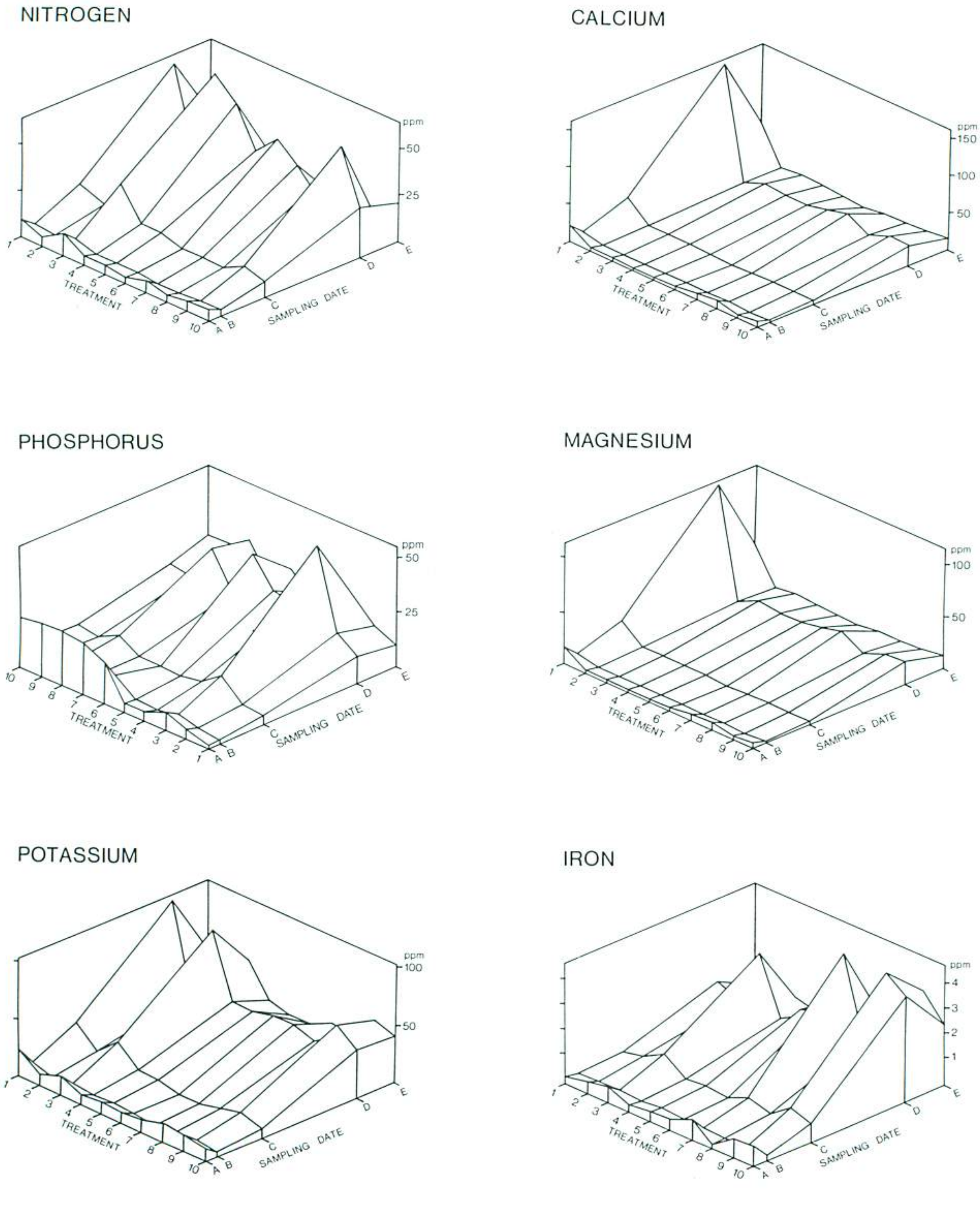

Figure 1. Concentrations of major elements in saturated extract of growing growing medium. (Refer to Table 1 for treatments.) Sampling date A = 28 July (after 10 applications of "starter"); B = 1 Aug. (after leaching); C = 15 Aug. (after six applications of "grower"); D = 14 Sept. (after 20 applications of "grower"); E = 26 Sept. (end of 12 week production period)

Seedling Growth Response

Despite large differences in supplied nutrients, no significant effects of treatments upon seedling growth or ontogeny were observed at any sampling date. In fact, seedling growth was remarkably uniform across all treatments for the entire 12-week greenhouse phase. The similarity of response is clearly illustrated in Figure 2, which superimposes all 10 growth progressions on a single graph. Individual treatments are not identified, partly because of the large amount of overlap and partly because the intent is to illustrate the similarity of treatment response. It will be noted that the Hocking solution, though formulated specifically for coniferous seedlings, produced no better growth than the commercial fertilizers; in fact, growth progressions for this treatment were usually the lowest.

Seedling dimensions at the time fertilizer treatments were terminated (12 weeks) are presented in Table 3. Although the average size of seedling was very similar from treatment to treatment, it should be noted that within-treatment variation in final dry weight was relatively high. This undoubtedly reflects the intense competition for aerial growing space that developed between the closely packed seedlings after the tenth week, leading to reduced growth in the less dominant individuals and their incipient suppression. From the viewpoint of cultural efficiency, this indicates that the optimum rotation had already been surpassed for the particular size of container used.

Growth rates were excellent by operational standards, supporting the view that, under constant fertilization, a 100 ppmN grower solution is adequate for crops of jack pine on a 10- to 12-week production cycle[3]. Faster growth can be achieved at higher concentrations, but experience has shown that this is usually at the expense of morphological seedling quality. While growth rate and plant size are important, the distribution of growth also needs to be considered. Even in summer crops, N levels over 100 ppm during the grower phase commonly lead to excessive shoot elongation and poor shoot:root balance in greenhouse-grown jack pine. Seedlings grown at 100 ppmN usually are shorter, sturdier and have a better root balance, notwithstanding the fact that, in this experiment, both 12-week height:diameter and shoot:root ratios were higher than desirable. With respect to the latter, it may be noted that, with the cessation of height growth, both ratios improved substantially between the time seedlings were moved from the greenhouse, on termination of the experiment, and the onset of winter.

The lack of any discernible or significant treatment response has important corollaries:

- Contrary to conventional wisdom, the use of special starter and finisher formulations with high P and K levels does not appear to have benefited seedling root development, or to have boosted the level of these elements in the foliage (see *Foliar Analysis*, p.12). General-purpose fertilizers were as effective in producing good quality, well balanced seedlings as the special "forestry" formulations.

---

[3]This assumes moisture conditions in the growing medium that allow for frequent additions of nutrient solution; where the medium is difficult to dry down, as in many winter crops, it may be necessary to adjust the fertilization method and rate.

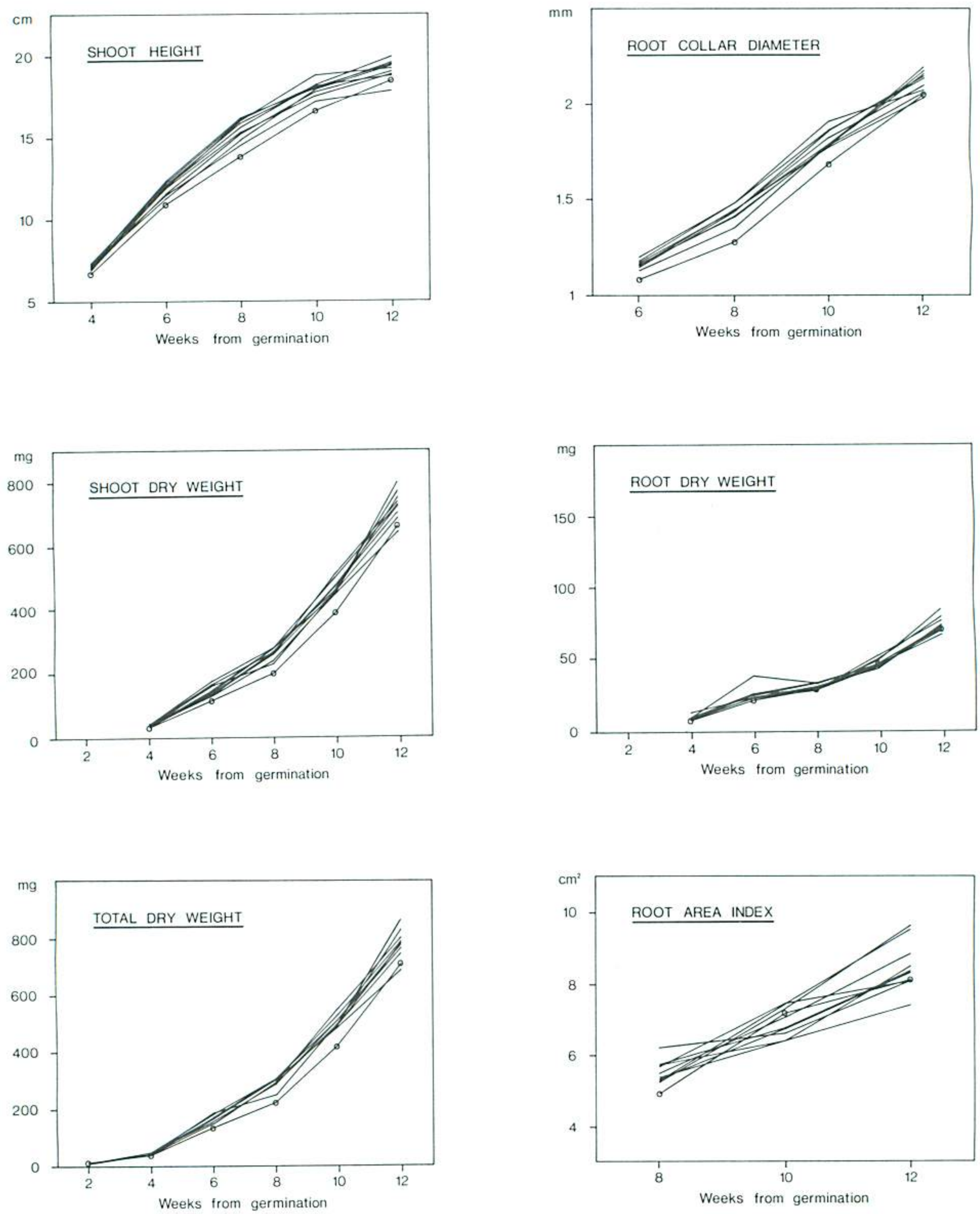

Figure 2. Growth progressions for jack pine seedlings grown under 10 fertilizer treatments, showing similarity of response. (Note: curve marked with circles denotes Hocking treatment.)

Table 3. Dimensions of 12-week-old jack pine paperpot seedlings grown under 10 different fertilizer regimes[a] (n = 25)

		Fertilizer treatment										Coeff. variation (%)
		1	2	3	4	5	6	7	8	9	10	
Shoot height (cm)	$\bar{x}$	18.5	18.7	18.8	19.9	19.3	19.4	19.5	17.9	19.0	19.4	11.4
	s	2.9	2.8	1.9	2.1	1.7	2.0	1.7	1.9	2.3	2.3	
Root-collar diam. (mm)	$\bar{x}$	2.1	2.0	2.1	2.1	2.1	2.1	2.2	2.2	2.1	2.2	15.6
	s	0.4	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.4	
Height:diam. ratio	$\bar{x}$	9.1	9.3	9.2	9.5	9.1	9.5	9.1	8.4	9.1	8.9	13.0
	s	1.2	1.1	1.4	1.2	1.4	1.2	1.2	1.3	1.2	0.8	
Shoot dry weight (mg)	$\bar{x}$	643	631	693	716	722	711	757	677	731	784	26.7
	s	160	193	175	229	159	184	205	176	178	227	
Root dry weight (mg)	$\bar{x}$	70	66	73	71	79	68	72	76	75	84	29.8
	s	19	23	24	20	24	22	23	23	17	23	
Total dry weight (mg)	$\bar{x}$	713	697	766	788	801	779	829	753	806	868	26.4
	s	173	208	195	247	179	203	225	195	190	245	
Shoot:root ratio	$\bar{x}$	9.3	9.9	9.9	10.0	9.4	10.8	10.8	9.2	9.9	9.5	18.3
	s	2.1	2.2	1.9	1.3	1.5	1.9	1.7	1.6	1.9	1.9	
Root area index (cm^2)	$\bar{x}$	8.1	8.1	8.3	8.1	9.5	7.4	8.5	8.9	8.4	9.6	29.0
	s	2.4	2.6	2.5	1.7	3.0	2.6	2.6	2.4	2.0	2.8	

[a] For each parameter, treatment differences are not significant at $p = 0.05$

[b] s = standard deviation

- Despite fairly substantial differences between fertilizer treatments (Appendix I) in proportions of urea, nitrate-N (NO_3-N) and ammonium-N (NH_4-N), the source of N was apparently unimportant for growth in this summer crop of jack pine. This agrees with Ingestad's (1979) finding that varied NH_4-N/NO_3-N ratios had little effect on growth of Scots pine and Norway spruce *(Picea abies* Karst.) seedlings. However, it must be admitted that N source studies with coniferous seedlings have produced conflicting results. While conifers have often been reported to respond best to NH_4-N (McFee and Stone 1968, van den Driessche 1971, Brix and van den Driessche 1974, Nelson and Selby 1974), others have reported better growth with NO_3-N (Pharis et al. 1964, Radwan et al. 1971) or with a mixture of these two N sources (Christersson 1972). These different responses may be related to species or to differences in moisture supply, soil temperature, pH, or the concentration of other nutrients. Consequently, it is not to be inferred that the results reported here will necessarily hold true for all crops of jack pine. In winter crops especially, where low light levels and cooler, wetter growing media with reduced oxygen levels may prevail, nitrification of NH_4-N may be inhibited. Because young seedlings, low in carbohydrates, may suffer ammonium toxicity if the NH_4-N level is too high (Bunt 1976), it might be safer to use high NO_3-N fertilizers (such as the Peters® 7-40-17 starter and 20-7-19 grower formulations) under these circumstances.

- Both constant and intermittent fertilization produced the same result. This was not entirely unexpected, although it should be noted that deliberate care was taken to ensure optimum moisture conditions and adequate nutrient flushing in the intermittent feed treatment. If such precautions are not taken there is perhaps a greater risk of soluble salt accumulation where fertilizers are applied periodically at high concentrations, with an attendant risk that seedlings may suffer reduced growth or injury, especially if the growing medium is allowed to dry out.

- Differences in micronutrient content between fertilizer treatments do not seem to have affected the development or growth of jack pine seedlings. Aside from a slight, transitory chlorosis of 6-week-old seedlings, perhaps caused by a minor Fe deficiency (see *Foliar Analysis*, p. 14), the general-purpose fertilizers (treatments 2, 3, 4, 6) performed, at least up to 12 weeks, just as well as the "forestry" fertilizers with the fortified microelement package, despite the fact that no supplemental micronutrients were added to the general-purpose fertilizers.

Foliar Analysis

For reference, foliar nutrient concentrations are summarized in full in Appendix V. With the exception of minor elements, these have been converted to absolute nutrient uptake values (concentration x mean shoot dry weight) to reflect better the relationship between fertilizer treatments (Fig. 3).

For the most part, nutrient uptake was fairly uniform from treatment to treatment at each sampling date. This parallels the absence of significant growth differences. With the exception of the high concentrations of Ca, Mn and B in treatment 1 (Hocking solution), those differences in uptake that were

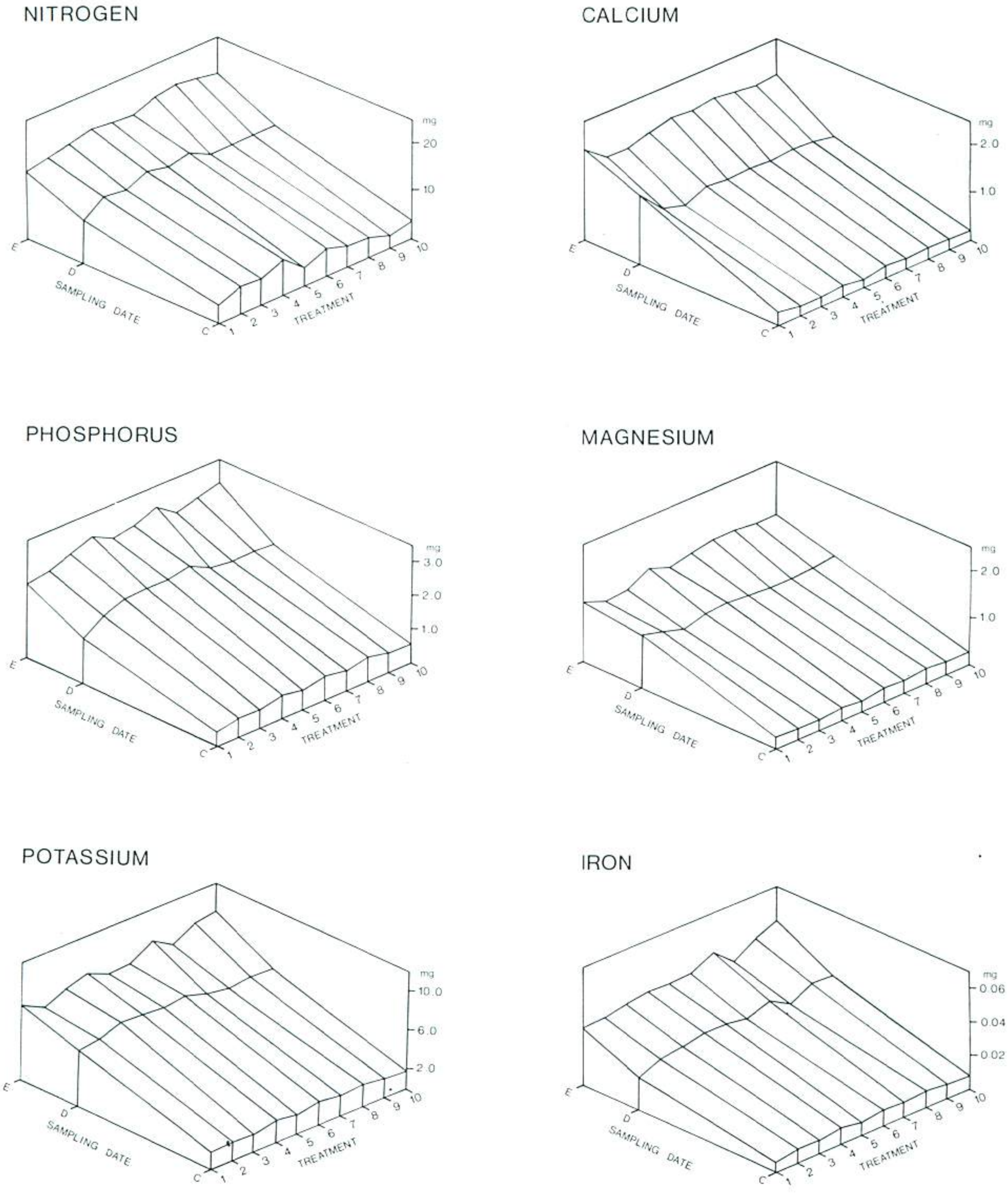

Figure 3. Foliar nutrient uptake by jack pine seedlings. (Refer to Table 1 for treatments.) Sampling date C = 15 Aug. (6 weeks); D = 14 Sept. (10 weeks - end of "grower" phase); E = 26 Sept. (12 weeks)

recorded (see 12-week data for P and K, Fig. 3) generally showed no clear relationship with nutrient concentrations in the fertilizer solution. Furthermore, there was generally poor correlation with nutrient concentrations in the growing medium (Table 4). Among commercial fertilizer treatments only foliar Fe showed any lasting association with nutrient levels in the growing medium, with final uptake in the "forestry" fertilizer treatments averaging 24% higher than that in the general-purpose treatments. Foliar values for Fe indicate that this element was on the borderline of deficiency in most of the general-purpose fertilizers. This would account for the mild chlorosis noted in these treatments at 6 weeks, although growth was unaffected. With a lower limit of 60 ppm, it seems that only the "forestry" fertilizer treatments had reasonably acceptable Fe concentrations at the end of the grower phase.

Table 4. Correlation coefficients (r) between growing nutrient concentrations at 10 weeks and foliar nutrient uptake at 10 and 12 weeks.

Element	Week 10	Week 12
	r	r
N	-0.205	0.216
P	0.603	-0.033
K	-0.129	0.005
Ca	0.894[a]	0.578
Mg	0.540[a]	-0.076
Fe	0.678	0.828

[a]High r-values for Ca and Mg were due to extreme data points contributed by treatment 1; without this treatment values were reduced to -0.119 and -0.028, respectively.

The nutrient content of plant tissues partly reflects the availability of nutrients in the growing medium and partly the ability of the plant to extract, translocate and assimilate those nutrients. The latter will vary with species, age of the plant, season, and other environmental factors (van den Driessche 1974). Consequently, care must be exercised when one is comparing foliar analysis results with values reported in the literature. While little published information is available that is specific to container stock, several sources cite values or ranges (Table 5) that can be used as a basis for evaluating results. These reveal no evident macronutrient deficiency in any of the present fertilizer treatments; indeed, at 10 and 12 weeks most were clearly close to the maximum of the ranges cited. (In this regard, it appears that the upper limits for P, K, Ca and Fe suggested by W.R. Grace [Table 5] may be rather high for jack pine.) Nitrogen values for actively growing 10-week-old seedlings were in agreement with Hallett's (1982b) guidelines for 10- to 16-week-old jack pine. However, it is of interest to note that, by the end of the finisher phase (i.e.,

Table 5. Foliar nutrient concentrations reported for jack pine seedlings and conifers in general.

Source	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)
1. <u>Jack pine</u>						
Hallett (1982b)[a]	2.5-3.0	-	-	-	-	-
Swan (1970)[b]	3.16	0.41	0.74	0.15	0.25	-
Weetman (1970)[c]	2.13	0.30	1.01	0.18	0.37	-
2. <u>General conifer ranges</u>						
W.R. Grace[d]	1.3-3.5	0.2-0.6	0.7-2.5	0.3-1.0	0.1-0.3	60-200
Ingestad (1960)[e]	2.4-3.1	0.13-0.28	0.7-1.6	0.01-0.3	0.12-0.2	50-70
Ingestad (1979)[f]	2.2	0.3	0.95	0.12	0.12	-
Powers (1974)[g]	1.3-3.0	0.1-0.3	0.5-1.6	0.12-0.7	0.07-0.2	50-100

[a] provisional guidelines for N concentrations in 10- to 16-week-old jack pine container stock

[b] 16-week-old jack pine seedlings grown in sand culture

[c] 40-week-old jack pine seedlings grown in shredded peat with Ingestad's nutrient solution

[d] normal ranges for conifer seedlings given on W.R. Grace & Co., Peters®/Terra-lite® Testing Laboratory analysis report form

[e] suggested optimum range for growth of Scots pine seedlings

[f] concentrations associated with maximum growth of 4- to 6-week old Scots pine seedlings

[g] adequacy range for coniferous seedlings

2 weeks later), N concentrations had already fallen below his range for hardening (2.5-2.8%) and were close to his recommended overwintering range (1.9-2.2%).

Contrary to the findings of Ingestad (1979), who reported an increase in the N content of seedlings with increasing ratio of NH_4-N to NO_3-N despite little effect on growth, no correlation was found between uptake of N and the N source in the grower fertilizer. Again, for reasons outlined in the previous section, it cannot be assumed that the same will hold true for all crops of jack pine, especially those grown as winter or early spring crops.

At optimum nutrition Ingestad (1967) concluded that "the proportions of elements in plants...seem to a great extent to vary insignificantly with species or age of plant, though the absolute concentrations and quantities may vary". Subsequently (1979) he proposed foliar nutrient proportions for maximizing growth of Scots pine (100 N; 14 P; 45 K; 6 Ca; 6 Mg) and Norway spruce (100 N; 16 P; 50 K; 5 Ca; 5 Mg). Weetman (1970) has published figures for 40-week-old jack pine (100 N; 14 P; 47 K; 17 Ca; 8 Mg) which, except for Ca, agree reasonably well with the Scots pine values. By contrast, element proportions computed from Swan's (1970) data for 16-week-old jack pine (Table 5) give low values for K (100 N; 13 P; 23 K; 5 Ca; 8 Mg). However, if we compare N:P:K ratios in the nutrient solutions used by Swan (1970) and Ingestad (1979) (100:10:10 and 100:13:65, respectively) it becomes clear that Swan's seedlings were inadequately supplied with K especially, and that suboptimal nutrition was the most probable reason for the lack of agreement in foliar element proportions.

Macronutrient proportions at the end of the present experiment (below) were in general accord with those reported (above) by Weetman (1970) and Ingestad (1979), a fact which lends support to the conclusion that all fertilizer treatments supplied adequate nutrients.

	10 weeks	12 weeks
N	100	100
P	15.4 ± 0.9	15.5 ± 1.0
K	53.5 ± 4.1	47.2 ± 4.0
Ca	9.1 ± 2.4 (8.4)	10.4 ± 1.1 (10.0)
Mg	8.5 ± 1.4 (8.1)	7.9 ± 0.5 (7.0)

It will be noted that, averaged over all treatments, values for K declined by roughly 12% during the finisher phase. Once again, high Ca and Mg values for treatment 1 elevate the overall means for these elements; average proportions for the commercial fertilizer treatments alone are given in parentheses.

General Discussion

From an operational viewpoint, these results reveal no particular biological advantage to using currently available "forestry" fertilizers, at the rates stated, in the summer production of 10- to 12-week-old jack pine container stock. In this regard, they proved no better and no worse than the general-purpose fertilizers or the Hocking solution. The similarity of response and vigor of growth indicates that, under the optimal conditions of this experiment, all treatments provided an adequate, if not abundant, supply of essential nutrients. This is borne out by the similarity of foliar nutrient uptake. With such unrestricted access to nutrients, and practically identical application rates of N, the principal driving force behind vegetative growth, it is perhaps not surprising that seedlings were insensitive to differences in fertilizer formulation.

The absence of nutrient supply stress can also explain the lack of any evident morphological response to the use of separate starter, grower and finisher fertilizers. Thus, it can be argued that the failure of high P starters to bring about any apparent improvement in root development was due to the fact that P levels were already sufficient in the other fertilizers. We must be cognizant, however, of the time element in the production of jack pine container stock, and the effect that this may have upon treatment response. For the most part, greenhouse periods are relatively short, in Ontario rarely exceeding 12 weeks. As a result, seedlings are exposed to a starter fertilizer, for example, for only a few weeks, probably too short a period for measurable treatment effects to develop unless there is some major nutrient deficiency.

It would be unwise to extrapolate the results of this experiment to older seedlings. Nutrient demand obviously increases as seedlings grow older and larger, and once demand exceeds supply, growth may be restricted. Swan (1970) cites a cautionary example. Experiments to investigate the relationship between nutrient supply and growth of black spruce (*Picea mariana* [Mill.] B.S.P.) and jack pine seedlings showed a striking difference in response to nutrient supply at 16 and 26 weeks. Had the experiments been terminated at 16 weeks it might have been concluded that there was little or no response. Ten weeks later the response was very pronounced. Thus, whereas it seems clear that none of the seedlings in the present experiment had grown big enough to encounter a nutrient supply stress, longer growing cycles might well have resulted in the development of progressively more pronounced treatment differences.

SUMMARY AND CONCLUSIONS

At the operationally conservative application rates used in this experiment, there were no significant differences in jack pine growth response or seedling ontogeny between fertilizer treatments at any sampling date. The similarity of foliar nutrient uptake supports the view that all treatments provided an adequate, if not abundant, supply of essential macro- and micronutrients.

The results provide no evidence to indicate that special starter, grower, and finisher formulations are necessary in the production of jack pine under optimum growing conditions. Under an assumed absence of nutrient supply stress, seedlings showed differences neither in morphological response nor in foliar nutrient uptake related to high-P starter or high-K finisher. In this regard, a simple 20-20-20 general-purpose formulation was just as effective as the "forestry" fertilizers for growing well balanced, vigorous seedlings.

In none of the treatments do micronutrient levels appear to have been limiting to the growth or development of 12-week-old seedlings, despite the fact that supplemental micronutrients were not added to the general-purpose fertilizers. However, in contrast to the "forestry" fertilizers, Fe levels were clearly on the borderline of deficiency in the general-purpose fertilizers. Thus, it is probably advisable to add supplementary iron chelate when using the latter.

It is concluded that all of the commercial fertilizers tested here are capable of producing, at the rates specified, vigorous summer crops of 12-week-old jack pine container stock. Under conditions similar to those of this experiment, the special "forestry" formulations do not appear to offer any particular biological advantage over general-purpose soluble fertilizers. However, there remains the possibility that different results might be obtained with winter crops, under less than optimum growing conditions, or in the production of larger seedlings.

Comparison of intermittent with constant fertilization treatments shows that both approaches can give equally good results, although intermittent feeding requires that particular attention be focussed on the maintenance of optimum moisture conditions in the growing medium and on the adequacy of nutrient flushing.

LITERATURE CITED

Boodley, J.W. and Sheldrake, R. Jr. 1982. Cornell peat-lite mixes for commercial plant growing. Cornell Univ., Agric. Exp. Stn., Coop. Ext. Serv., Ithaca, N.Y. Inf. Bull. 43. 8 p.

Brix, H. and van den Driessche, R. 1974. Mineral nutrition of container-grown tree seedlings. p. 73-84 *in* R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.*, Proc. North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Bunt, A.C. 1976. Modern potting composts. A manual on the preparation and use of growing media for pot plants. Penn. State Univ. Press. 277 p.

Christersson, L. 1972. The influence of urea and other nitrogen sources on growth rate of Scots pine seedlings. Physiol. Plant. 27:83-88.

Edwards, I.K. and Huber, R.F. 1982. Contrasting approaches to containerized seedling production. 2. The Prairie provinces. p. 123-127 *in* J.B. Scarratt, C. Glerum and C.A. Plexman, *Ed.*, Proc. Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-10.

Hallett, R.D. 1982a. Contrasting approaches to containerized seedling production. 3. The Maritime provinces. p. 129-138 *in* J.B. Scarratt, C. Glerum and C.A. Plexman, *Ed.*, Proc. Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-10.

Hallett, R.D. 1982b. Monitoring crop development during the rearing of containerized seedlings. p. 245-253 *in* J.B. Scarratt, G. Glerum and C.A. Plexman, *Ed.*, Proc. Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-10.

Hocking, D. 1971. Preparation and use of a nutrient solution for culturing seedlings of lodgepole pine and white spruce, with selected bibliography. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-1. 13 p.

Hocking, D. 1972. Comparison of proprietary with prescription nutrient solutions for Alberta white spruce and lodgepole pine. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-35. 19 p.

Ingestad, T. 1960. Studies in the nutrition of forest tree seedlings. III Mineral nutrition of pine. Physiol. Plant. 13:513-533.

Ingestad, T. 1962. Macroelement nutrition of pine, spruce and birch seedlings in nutrient solutions. Medd. Statens. Skogsforskningsinst. 51(7):1-150.

Ingestad, T. 1967. Methods for uniform optimum fertilization of forest tree plants. Proc. 14th IUFRO Congr., Munich. Vol. III:265-269.

Ingestad, T. 1979. Mineral nutrition requirements of *Pinus silvestris* and *Picea abies* seedlings. Physiol. Plant. 45:373-380.

Matthews, R.G. 1982. Contrasting approaches to containerized seedling production. 1. British Columbia. p. 115-122 *in* J.B. Scarratt, C. Glerum and C.A. Plexman, *Ed.*, Proc. Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-10.

McFee, W.W. and Stone, E.L. 1968. Ammonium and nitrate as nitrogen sources for *Pinus radiata* and *Picea glauca*. Soil Sci. Soc. Amer. Proc. 32:879-884.

Morrison, I.K. and Armson K.A. 1968. The rhizometer - a device for measuring roots of tree seedlings. For. Chron. 44:21-23.

Nelson, L.E. and Selby, R. 1974. The effect of nitrogen sources and iron levels on the growth and composition of Sitka spruce and Scots pine. Plant and Soil 41:573-588.

Pharis, R.P., Barnes, R.L. and Naylor, A.W. 1964. Effects of nitrogen level, calcium level, and nitrogen source upon growth and composition of *Pinus taeda* L. Physiol. Plant. 17:560-572.

Powers, R.F. 1974. Evaluating fertilizer programs using soil analysis, foliar analysis and bioassay methods. p. 124-151 *in* Proc. Service-wide Work Conf., Sacramento, Calif. USDA For. Serv., Div. Timber Manage., Washington, D.C. [cited in Landis, T.D. 1977. Analysis and interpretation of foliage nutrient levels in tree seedlings. p. 111-116 *in* W.L. Loucks, *Ed.*, Proc. Meet. Intermountain Nurserymen's Assoc., Manhattan, Kansas, 1977].

Puustjärvi, V. 1977. Peat and its use in horticulture [Transl. W.A. Krause] Turveteollisuusliitto ry. Publ. 3. 160 p.

Radwan, M.A., Crough, G.L. and Ward, H.S. 1971. Nursery fertilization of Douglas-fir seedlings with different forms of nitrogen. Pacific Northwest For. and Range Exp. Stn., Portland, Oreg. USDA For. Serv., Res. Pap. PNW-113. 8 p.

Shadan, M.M. and Peters, J.R. 1981. Plant tissue analysis. W.R. Grace and Co. Horticultural Products, Cambridge, Mass. Benchmarks 1(8):3.

Swan, H.S.D. 1970. Relationships between nutrient supply, growth and nutrient concentrations in the foliage of black spruce and jack pine. Pulp Paper Res. Inst. Can., Woodl. Pap. No. 19. 46 p.

Tinus, R.W. and McDonald, S.E. 1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Rocky Mountain For. and Range Exp. Stn., Gen. Tech. Rep. RM-60. 256 p.

van den Driessche, R. 1971. Response of conifer seedlings to nitrate and ammonium sources of nitrogen. Plant and Soil 34:421-439.

van den Driessche, R. 1974. Prediction of mineral nutrient status of trees by foliar analysis. Bot. Rev. 40(3):347-394.

Weetman, G.F. 1970. A trial of a new hydroponic system for the production of black spruce and jack pine seedlings. Pulp Paper Res. Inst. Can., Woodl. Pap. No. 17. 15 p.

Whitcomb, C.E. 1984. Plant production in containers. Lacebark Publications, Stillwater, Okla. 638 p.

APPENDICES

Appendix I. Analysis of 11 commercial fertilizer formulations used for growing jack pine[a]

Fertilizer make	Formulation	Description[a]	Fertilizer analysis (%)												
			Urea	NH_4[b]	NO_3[c]	Total N	P[d]	K[e]	Mg	Mn	Fe	Cu	B	Zn	Mo
Peters	7-40-17	Conifer starter	0.23	3.35	3.42	7.0	40.0	17.0	0.15	0.03	0.20	0.03	0.015	0.03	0.003
Peters	9-45-15	Plant starter	-	9.00	-	9.0	45.0	15.0	0.05	0.0031	0.05	0.0036	0.0068	0.0025	0.0009
Pl. Prod.	10-52-10	Plant starter	1.30	7.80	0.90	10.0	52.0	10.0	-	0.05	0.10	0.05	0.02	0.05	0.0005
Pl. Prod.	11-41-8	Forestry seedling starter	-	9.50	1.50	11.0	41.0	8.0	0.15	0.05	0.20	0.05	0.02	0.05	0.0005
Peters	20-7-19	Conifer grower	1.40	7.00	11.60	20.0	7.0	19.0	0.30	0.06	0.40	0.06	0.025	0.06	0.005
Pl. Prod.	20-8-20	Forestry seedling special	11.00	4.00	5.00	20.0	8.0	20.0	0.15	0.05	0.40	0.05	0.02	0.05	0.0005
Peters	20-19-18	Peat-lite special	11.05	3.75	5.20	20.0	19.0	18.0	0.15	0.056	0.10	0.01	0.02	0.0162	0.01
Peters	20-20-20	General purpose	10.43	3.96	5.61	20.0	20.0	20.0	0.05	0.0031	0.05	0.0036	0.0068	0.0025	0.0009
Pl. Prod.	20-20-20	All purpose	10.25	3.85	5.90	20.0	20.0	20.0	-	0.05	0.10	0.05	0.02	0.05	0.0005
Peters	4-25-35	Conifer finisher	2.96	1.04	-	4.0	25.0	35.0	0.30	0.06	0.40	0.06	0.025	0.06	0.005
Pl. Prod.	8-20-30	Forestry seedling finisher	-	2.70	5.30	8.0	20.0	30.0	0.15	0.05	0.30	0.05	0.02	0.05	0.0005

[a] As given in manufacturers' brochures and bulletins

[b] Ammoniacal nitrogen

[c] Nitrate nitrogen

[d] Available P_2O_5

[e] Soluble K_2O

Appendix II. Fertilizer application rates by treatment

Treatment no.	Fertilizer type	Fertilizer make	Formulation	Application Rate (elemental ppm)										
				N	P	K	Ca	Mg	Mn	Fe	Cu	B	Zn	Mo
1	starter	-	Hocking	56	15.50	78.00	40.0	24.50	0.215	2.500	0.010	0.195	0.025	0.005
	grower	-	Hocking	112	31.00	156.00	80.0	49.00	0.430	5.000	0.020	0.390	0.050	0.010
	finisher	-	Hocking	56	15.50	78.00	40.0	24.50	0.215	2.500	0.010	0.195	0.025	0.005
2	starter	Pl. Prod.	20-20-20	50	21.82	41.51	-	-	0.125	0.250	0.125	0.050	0.125	0.001
	grower	Pl. Prod.	20-20-20	100	43.64	83.02	-	-	0.250	0.500	0.250	0.100	0.250	0.002
	finisher	Pl. Prod.	20-20-20	25	10.91	20.75	-	-	0.062	0.125	0.062	0.025	0.062	0.001
3[a]	starter	Pl. Prod.	20-20-20	150	65.46	124.53	-	-	0.375	0.750	0.375	0.150	0.375	0.004
	grower	Pl. Prod.	20-20-20	300	130.92	249.06	-	-	0.750	1.500	0.750	0.300	0.750	0.007
	finisher	Pl. Prod.	20-20-20	75	32.73	62.26	-	-	0.187	0.375	0.187	0.075	0.187	0.002
4	starter	Peters	20-20-20	50	21.82	41.51	-	0.12	0.008	0.125	0.009	0.017	0.006	0.002
	grower	Peters	20-20-20	100	43.64	83.02	-	0.25	0.015	0.250	0.018	0.034	0.012	0.004
	finisher	Peters	20-20-20	25	10.91	20.75	-	0.06	0.004	0.062	0.004	0.008	0.003	0.001
5	starter	Peters	20-19-18	50	20.73	37.36	-	0.37	0.140	0.250	0.025	0.050	0.040	0.025
	grower	Peters	20-19-18	100	41.46	74.72	-	0.75	0.280	0.500	0.050	0.100	0.081	0.050
	finisher	Peters	20-19-18	25	10.36	18.68	-	0.19	0.070	0.125	0.012	0.025	0.020	0.012
6	starter	Pl. Prod.	10-52-10	50	113.46	41.51	-	-	0.250	0.500	0.250	0.100	0.250	0.002
	grower	Pl. Prod.	20-20-20	100	43.64	83.02	-	-	0.250	0.500	0.250	0.100	0.250	0.002
	finisher	Pl. Prod.	10-52-10	25	56.73	20.75	-	-	0.125	0.250	0.125	0.050	0.125	0.001
7[b]	starter	Pl. Prod.	11-41-8	50	81.33	30.19	-	0.68	0.227	0.909	0.227	0.091	0.227	0.002
	grower	Pl. Prod.	20-8-20	100	17.46	83.02	-	0.75	0.250	2.000	0.250	0.100	0.250	0.002
	finisher	Pl. Prod.	8-20-30	25	27.27	77.83	-	0.47	0.156	0.937	0.156	0.062	0.156	0.002
8	starter	Peters	9-45-15	50	109.10	69.18	-	0.28	0.017	0.278	0.002	0.038	0.014	0.005
	grower	Peters	20-19-18	100	41.46	74.72	-	0.75	0.280	0.500	0.050	0.100	0.081	0.050
	finisher	Peters	9-45-15	25	54.55	34.59	-	0.14	0.009	0.139	0.001	0.019	0.007	0.002
9[b]	starter	Peters	7-40-17	50	124.69	100.81	-	1.07	0.214	1.428	0.214	0.107	0.214	0.021
	grower	Peters	20-7-19	100	15.24	78.87	-	1.50	0.300	2.000	0.300	0.125	0.300	0.025
	finisher	Peters	4-25-35	25	68.19	181.61	-	1.87	0.375	2.500	0.375	0.156	0.375	0.031
10[b]	starter	Pl. Prod.	11-41-8	50	81.33	30.19	-	0.68	0.227	0.909	0.227	0.091	0.227	0.002
	grower	Pl. Prod.	20-8-20	100	17.46	83.02	-	0.75	0.250	2.000	0.250	0.100	0.250	0.002
	finisher	Pl. Prod.	8-20-30	50	54.55	155.66	-	0.94	0.312	1.875	0.312	0.125	0.312	0.003

[a] Intermittent feed program (all other treatments on constant fertilization)

[b] "Forestry" formulations

Appendix III. Chemical analyses of irrigation water and peat: vermiculite growing medium

	Irrigation water[a]		Growing medium[b]
	Sample A	Sample B	
pH	8.14	8.20	4.06
Soluble salts (mmhos 10^{-5})	0.29	0.29	0.10
Chlorides (ppm)	58.9	57.1	N
NH_4 nitrogen (ppm)	0	0	1.56
NO_3 nitrogen (ppm)	1.21	0	0
Total N (ppm)	1.21	0	1.56
P (ppm)	0.143	0	1.30
K (ppm)	2.42	2.58	5.19
Ca (ppm)	40.7	39.0	1.83
Mg (ppm)	6.19	5.92	1.19
Mn (ppm)	0.022	0.019	0.046
Fe (ppm)	0.054	0.044	0.143
Cu (ppm)	0.009	0.019	0
B (ppm)	0.115	0.122	0.031
Zn (ppm)	0	0.001	0.002
Mo (ppm)	0.009	0.010	0.010
Al (ppm)	0.023	0.027	N
Na (ppm)	20.4	21.3	N

[a] Sault Ste. Marie city water; samples taken 48 hours apart

[b] Sampled at filling line before beginning of experiment

N = not measured

Appendix IV. Growing medium analysis for 14 September (10 weeks from germination; following 20 applications of "grower" fertilizer)

Treatment	N ppm	P ppm	K ppm	Ca ppm	Mg ppm	Mn ppm	Fe ppm	Cu ppm	B ppm	Zn ppm	Mo ppm	Al ppm	Na ppm	pH	Salts (mmhos)
1	57.8	13.5	97.9	158.0	111.0	0.855	1.37	0	0.349	0.226	0.019	1.010	54.0	3.72	2.16
2	17.8	19.7	27.2	10.1	7.7	0.092	1.07	0	0.088	0	0.012	0.354	30.3	4.38	0.30
3	62.3	55.5	84.7	21.0	17.3	0.180	3.07	0.04	0.161	0.059	0.008	0.339	45.9	4.43	0.80
4	51.2	24.5	34.5	19.2	14.7	0.171	1.01	0	0.092	0.012	0.017	0.505	43.2	4.14	0.52
5	31.9	26.6	34.5	18.9	14.7	0.194	1.71	0	0.126	0.019	0.011	0.574	48.1	4.11	0.58
6	42.7	39.1	38.7	24.8	18.9	0.199	2.21	0	0.148	0.03	0.010	0.498	46.9	4.09	0.59
7	34.0	17.9	38.9	32.8	24.5	0.303	4.41	0	0.133	0.060	0.010	0.648	51.8	4.00	0.79
8	29.8	33.4	33.6	17.0	12.5	0.158	1.64	0	0.114	0.004	0.010	0.427	41.8	4.12	0.50
9	53.7	16.4	53.8	28.2	20.7	0.260	4.39	0	0.141	0.062	0.011	0.537	51.4	4.14	0.70
10	26.3	18.1	41.8	28.5	22.2	0.262	3.84	0	0.133	0.041	0.008	0.586	49.5	4.09	0.70

Appendix V. Foliar nutrient analyses (concentration)

Treatment no.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)	Mo (ppm)	Al (ppm)	Na (ppm)
15 August - 6 weeks													
1	3.3	0.367	1.43	0.234	0.223	49.9	200	4.00	45.9	69.0	0	-	-
2	4.1	0.398	1.32	0.142	0.164	57.3	111	3.83	33.5	61.7	0.326	-	-
3	3.9	0.393	1.25	0.148	0.155	54.9	115	3.99	36.0	61.8	0.423	-	-
4	4.4	0.401	1.33	0.148	0.162	54.4	110	3.56	32.2	61.4	0.326	-	-
5	2.8	0.425	1.45	0.130	0.161	53.6	102	3.56	33.6	59.6	0.364	-	-
6	3.6	0.450	1.48	0.165	0.181	58.9	128	4.27	39.4	82.1	0.345	-	-
7	3.1	0.416	1.48	0.152	0.174	57.1	115	3.87	37.7	71.5	0.344	-	-
8	2.6	0.452	1.41	0.154	0.190	58.5	109	3.77	36.5	65.0	0.383	-	-
9	2.0	0.447	1.54	0.176	0.190	63.8	127	4.61	40.9	73.3	0.519	-	-
10	2.9	0.421	1.38	0.151	0.181	59.8	132	4.26	39.5	74.7	0.441	-	-
14 September - 10 weeks													
1	2.4	0.351	1.49	0.378	0.289	50.1	188	3.96	61.5	63.1	1.02	214	215
2	2.7	0.392	1.36	0.230	0.226	57.0	154	5.17	39.1	68.8	1.02	259	231
3	2.5	0.428	1.48	0.190	0.182	57.7	108	6.28	37.2	68.1	1.32	196	279
4	2.8	0.411	1.40	0.224	0.204	61.1	149	4.22	34.8	63.2	1.13	276	286
5	2.5	0.402	1.30	0.198	0.207	59.3	137	4.52	38.4	68.6	1.36	282	245
6	2.9	0.458	1.48	0.228	0.213	59.1	141	5.46	40.8	84.1	1.44	257	263
7	2.5	0.403	1.36	0.222	0.213	72.8	166	5.11	40.6	72.6	1.25	283	261
8	2.5	0.388	1.29	0.239	0.215	56.9	150	4.49	41.3	64.0	1.17	244	244
9	2.5	0.400	1.36	0.229	0.223	73.0	157	5.58	40.1	74.4	1.29	262	223
10	2.6	0.379	1.36	0.217	0.235	71.7	150	5.67	39.3	67.8	0.98	274	268
26 September - 12 weeks													
1	2.2	0.347	1.18	0.296	0.197	52.8	150	4.72	44.5	47.3	0.72	200	275
2	2.4	0.368	1.04	0.247	0.176	56.2	109	4.98	30.4	56.1	1.15	219	257
3	2.3	0.370	1.09	0.221	0.169	55.5	108	4.46	31.2	55.3	1.67	137	277
4	2.4	0.395	1.15	0.233	0.200	55.7	110	3.90	29.2	58.3	1.07	223	230
5	2.3	0.346	1.01	0.251	0.173	53.6	114	4.04	32.9	52.1	1.50	244	213
6	2.3	0.369	1.05	0.248	0.191	55.9	114	4.65	35.7	64.3	0.98	220	224
7	2.4	0.385	1.17	0.244	0.191	62.8	122	5.22	33.6	59.1	1.03	236	314
8	2.8	0.366	1.12	0.260	0.214	52.7	123	4.62	36.1	57.0	1.24	226	263
9	2.5	0.364	1.21	0.234	0.192	62.3	114	4.94	31.8	62.6	1.07	238	212
10	2.2	0.363	1.17	0.222	0.178	63.4	111	4.74	33.2	60.9	0.85	232	295