Effects of Contrasting Fertilizer Regimes on Greenhouse Growth and Outplant Performance of Containerized Jack Pine

G.S. Henderson, W. Smith, B. Nicks [1]

Henderson, G.S.; Smith, W.; Nicks, B. 1994. Effects of Contrasting Fertilizer Regimes on Greenhouse Growth and Outplant Performance of Containerized Jack Pine. In Landis, T.D.; Dumroese, R.K., technical coordinators. Proceedings, Forest and Conservation Nursery Associations. 1994, July 11-14; Williamsburg, VA. Gen. Tech. Rep. RM-GTR-257. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 130-138. Available at: http://www.fcnanet.org/proceedings/1994/henderson.pdf

Abstract—Jack pine seedlings were raised in Jiffy #165 containers at nine fertilizer regimes to assess whether pre-plant characteristics could be related to subsequent outplant performance. Seedlings received a top dressing of between 0 and 49 mg N per seedling over a twelve week greenhouse growing period in the summer of 1989. At rotation end, only the two lowest fertilizer regimes, representing less than 4.1 mg N per seedling,displayed significantly decreased height, diameter, and total dry weight. Toxic growth response to high N levels was not detected. Three years after planting on a sandy outwash site, seedling stem volume was significantly higher in fertilizer treatments which delivered more than 11 mg N per seedling. Stem volume increase was 20-58 % more than the conventional regime of 8.1 mg N per seedling. Field growth was positively related (R^2 = 0.82) with increasing shoot to root ratios of seedlings at the greenhouse; coeffcient of determination was much weaker with all other preplant seedling parameters. Nitrogen content in seedlings also showed a high positive coefficient of determination (R^2 = 0.71) with field performance. The greatest plantation response was evident in seedlings that contained 31% more nitrogen than conventional seedlings prior to planting. It is postulated that N content is the more useful predictor of seedling outplant performance as it is a robust measure of pre-plant seedling size and nutrient status. Our results indicate that jack pine seedlings be reared under regimes which deliver more than 11 mg N per seedling to induce luxury consumption of fertilizer in tissue, which effectively 'loads' seedlings with nitrogen at greenhouse rotation end and stimulates enhanced growth after planting. Additionally,the build up of a nutrient reserve by high fertilizer regimes prior to planting offers a cost-efficient and specialized advantage to jack pine seedlings over site vegetation competing for early establishment in sandy plantations. The utility of high N fertilizer application in enhancing early field performance of jack pine along with the facility of implementing such luxury consumption fertilizer regimes in the greenhouse suggests that N content is a beneficial complementary parameter for assessing seedling quality in containerised stock programmes.

INTRODUCTION

The efficient use of N-fertil-Izer is an important objective in container tree nutrient regimes as it is typically the element most utilized by plants and frequently limits growth of seedlings (Landis 1989).

A wide array of N-fertilizer regimes, however, can produce healthy, plantable, greenhouse-cultured container tree seedlings. Scarratt (1986), for example, found that any of 10 different fertilizer treatments applied at 100 ppm N to jack pine yielded similar seedling morphology, with no apparent advantage conferred by special forestry

[1] Jiffy Products (NB) Ltd, Shippagan, N.B.E0B 2P0; Mikro-Tek Labs, Timmins,Ont. P4N 7X8; E.B. Eddy Forest Products Ltd., Espanola,Ont. P0P 1C0. Canada; respectively.

mixes or starter and finishing preparations, despite large differences in supplied nutrients. Columbo and Smith (1988) measured greatest shoot, diameter and root dry weight in containerised jack pine which corresponded to 9.19 mg N/ seedling and 1.91-2.33% foliar N. Timmer and Armstrong (1987) found that 10 mg N/ seedling applied to red pine in An exponential fashion resulted in superior seedling height, dry matter production and root development. Others (Burgess 1990, Troeng and Aczell 1988) have also found advantages in applying fertilizer to seedlings in an exponential fashion during the rapid growth phase, particularly as a means of increasing root development and lowering shoot to root ratios.

However, few container seedling fertilizer programmes are assessed in terms of resultant field performance. Timmer et al. (1991) found that containerised black spruce seedlings raised on an exponential fertilizer regime had significantly greater growth than those on a conventional regime, one year after planting seedlings in pots filled with forest soils. Black spruce seedlings 'loaded' in the greenhouse attained foliar N% of 2.68 and resulted in significantly greater height and dry matter production one season after outplanting (Timmer and Munson 1991). In a review, Landis (1985) found that while nursery fertilization does not necessarily affect seedling survival after out planting, seedling growth was strongly positively related to pre-plant fertilizer regimes for a variety of coniferous species.In particular, pre-plant foliar N levels were the best indicators of out plant seedling height development, with R-squared values reaching 0.84.

The present investigation follows the field survival and growth of jack pine container seedlings that developed under a variety of nitrogen fertilization treatments.

MATERIALS AND METHODS

Jack pine *(Pinus banksiana* Lamb.) seedlings grew in a plastic covered greenhouse at Northern Greenhouse Farms, Iroquois Falls, Ontario, Lat. 48 degrees 46 minutes north, Long. 80 degrees 41 minutes west. The seedlings were sown on June 26, 1989 into Jiffy Forestry Pellets type #165 (Jiffy Products (N.B.) Ltd., Shippagan, New Brunswick at a density of 910 pellets/m ^{2} . Each pellet was approximately 7.5cm in height and 30mm in diameter and contained 45m ^{3} of peat moss amended to a pH of 4.5 and electrical conductivity of 1.0 millimos. Jiffy pellets are covered by a mesh net which compartmentalizes cavities.

Seedlings developed under natural daylight. Greenhouse conditions ranged from night minimum to day maximum temperatures of 15-20 Celsius. Twenty-seven trays (1 tray = 330 pellets) were arranged on benches in a randomized block design (8,910 total seedlings) such that each of nine fertilizer treatments was replicated three times, with each tray representing one treatment.

Seedlings were fertilized using the following treatments of differing concentrations of N:1.0x, water only (0 ppm N); 2. 1/2x, (50 ppm N); 3.1x, (100 ppm N); 4. 1.2x, (120 ppm N); 5. 1.4x, (140 ppm N); 6. 2x, (200 ppm N); 7. 6x, (600 ppm N); 8. 1/2Ex (half exponential rate); and 9. Ex (full exponential rate). X refers to a rate of 100 ppm N, frequently applied to jack pine seedlings on an operational basis in Northern Ontario. Exponential rates were established using the function of Ingestaad and Lund (1979):

$$\mathbf{Nt = Ns(e^{rt} -1)}$$

where,

Nt = amount of N to be added weekly (ppm N)

Ns = start N (5 ppm N)

r = relative addition rate (daily addition rates of N are 6% for Ex and 3% for 1/2 Ex)

t = frequency of relative addition rate (7 days).

The value for Ns was established from Timmer and Armstrong (1987). Nitrogen was supplied as 12% NO_3^-, 8% NH_4^+ , from a water soluble 20-8-20 Plant Products Forestry growing

-phase mix, applied by a hand-held watering can to each tray, starting three weeks after germination and continuing for twelve weeks. A starter fertilizer of 11-41-8 (100 ppm N) was applied once every two weeks after germination to all treatments except 0x. Fertilizer was applied weekly, with supplemental irrigation as required to prevent seedlings from reaching their wilting point. Seedling germination was considered complete on June 26, based on tested seed viability and vigour.

Fifteen weeks after germination, seedlings were measured and samples collected. Ten seedlings were randomly extracted from each tray and measured for height from root collar to bud tip, root collar diameter, and then oven dried for total dry weight. The first two rows and columns of trays were not sampled to provide a buffer against edge effects. Thirty seedlings per treatment were recorded. Differences between treatments were compared using ANOVA and the Least Significance Difference Test (Snedcor & Cochran 1980).

Percentage N in foliage was determined from a composite sample of three randomly selected, then oven dried, seedlings per treatment by the Kjeldahl method (Bremner and Mulvaney 1982) at the Hugh John Flemming Forestry Complex in Fredericton, N.B.

After measurements, seedlings were moved in trays to an outside holding area in the same design as in the greenhouse to harden and overwinter under snow. No further fertilization was applied prior to shipping seedlings for planting the following spring.

FIELD

Seedlings were planted on June 14, 1990 by E.B. Eddy Forest Products Ltd. of Espanola, Ontario at the Upper Spanish Forest, Lat. 47 degrees, 28 minutes north, Long. 81 degrees 50 minutes west.

The site is a level, glaciofluvial outwash plain, characterized by deep, rapidly drained coarse sands capped with 20 cm of well-drained sandy loam. Organic horizons average only 2.5 cm in thickness. Due to a weakly developed Ae horizon, this soil is classified as Mini Humo-Ferric Podzols (Anon., 1974).

Lesser vegetation includes low-bush blueberry *(Vaccinium angustifolium* Ait.), trailing arbutus *(Epigaea repens* L.), wintergreen *(Gaultheria procumbens* L.), bearberry *(Arctostaphylos uva-ursi* (L.) Spreng.), and club lichens *(Cladina* spp.). These species are all indicative of dry, relatively infertile site conditions (Sims et al., 1989).

Seedlings were carefully planted at 2.0 metre spacing within furrows prepared by a TTS Delta hydraulic disc trencher. The experimental design consisted of a randomized complete block having 10 replications of 5-tree row plots for each of the 9 fertilizer treatments. Thus, a total of 50 seedlings from each treatment was planted, for a total of 450 seedlings.

Seedlings were measured annually each fall from 1990 to 1993 for total height and diameter at one-third of stem height. Stem volumes were estimated using the formula for a paracone developed by Forslund (1982) and later verified for jack pine (Forslund and Patterson 1994). Data was examined by one-way ANOVA and Least Significant Difference tests to determine treatment effects.A composite sample of 10 randomly selected, then oven dried, seedlings per treatment were collected for determination of % foliar N.

RESULTS

Greenhouse:

The amount of nitrogen supplied to seedlings by the nine fertilizer treatments ranged from 0 to approximately 49 mg per seedling over the twelve week fertilizer period (Table 1). Approximately 32% of the fertilizer passed between pellets and did not enter into calculations of applied N. The 'x' or operational N level of 100 ppm N delivered 8.1 mg N/seedling.

There was no significant increase in seedling height, diameter, shoot dry weight or total dry weight beyond the 1/2x fertilizer treatment, corresponding to a rate of 4.1 mg N / seedling (Table 1). Only the 0x and 1/2Ex treatments, delivering 0 and 1.6 mg N per seedling, respectively, were associated with significantly decreased morphology and pronounced deficiency symptoms of stunted growth and needle chlorosis. Seedlings in all other treatments met accepted Ontario Ministry of Natural Resources standards for height and root collar diameter.

Root dry weight showed a decreasing trend as fertilizer application amounts were increased. Significantly lower weights were for seedlings grown at rates of more than 11.4 mg N.

Shoot to root ratios also increased with increasing fertilizer amounts. Ratios ranged from 2.1 at the water only treatment to 7.2 for seedlings in the 6x treatment. Significantly highest ratios were for seedlings in the 2x and 6x treatments, which received more than 16 mg N per seedling.

Foliar N concentrations in seedling needles increased linearly from 1 % in the water-only treatment up to a maximum of nearly 3 % for the 2x and 6x treatments (Figure 1). The exception to this trend was the Ex treated seedlings, which showed a slight but non-significant increase in % N over seedlings in the higher N-applied x treatment. This verifies the high fertilizer levels at crop rotation end in the exponential regime and accounts for greener needles heading into the over wintering stage (Table 1).

On the basis of expression of seedling morphology and defined in terms of nutrient uptake patterns (Landis 1985), deficiency growth symptoms were evident at an N applied amount of less than 4 mg per seedling. Optimum -luxury consumption was in the wide range of 4 - 48 mg applied N per seedling, as plants were able to uptake additional fertilizer without any reduction in morphology and total biomass. Above applied rates of 16 mg N per seedling, percentage N in needles remained stable at 2.9, despite increased availability. Toxic growth response to high N was not observed and is therefore above 48 mg N per seedling.

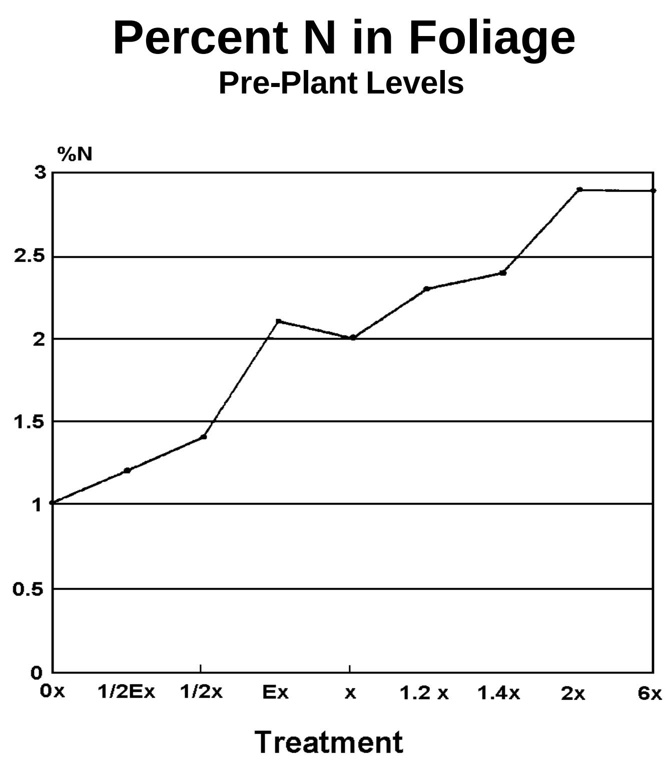

Figure 1

Table 1. Amount of N applied by treatment and growth response of seedlings at greenhouse rotation end. Columns followed by the same letter are not statistically different at p = 0.05.

Fertilizer Level	0%	1/2Ex	1/2x	Ex	x	1.2x	1.4x	2x	6x
N applied (mg/seedling)	0	1.6	4.1	5.9	8.1	9.7	11.4	1C.2	48.7
Foliar N (%)	1	1.2	1.4	2.1	2	2.3	2.4	2.9	2.9
N content (mg)	1.7	2.4	3.7	6.0	6.4	7.5	6.S	7.8	8.4
Height (mm)	53.9 (b)	75.3 (b)	106.3 (a)	108.8 (a)	115.9 (a)	124.1 (a)	111.9 (a)	118.5 (a)	118.4 (a)
Diameter (mm)	1.0 (b)	1.1 (b)	1.3 (a)	1.4 (a)	1.4 (a)	I.5 (a)	1.4 (a)	1.4 (a)	1.5 (a)
Ht:Dia	52.5 (c)	66.0 (bc)	78.8 (ab)	78.1 (ab)	79.7 (ab)	82.9 (a)	8L8 (ab)	82.3 (ab)	80.1 (ab)
Root weight(mg)	54.0 (ab)	57.0 (a)	53.6 (ab)	55.1 (a)	53.8 (ab)	50.0 (ab)	43.8 (abc)	40.2 (bc)	35.6 (c)
Shoot weight (mg)	112.3 (c)	141.2 (b)	212.9 (a)	231.2 (a)	268.0 (a)	274.8 (a)	227.1 (a)	228.7 (a)	256.0 (a)
Shoot:root	2.1 (e)	2.4 (d)	4.0 (cd)	4.2 (bc)	4.9 (bc)	5.3 (bc)	S.1 (bc)	S.7 (ab)	7.2 (a)
Total weight (mg)	166.3 (c)	198.2 (bc)	266.5 (ab)	286.3 (a)	321.7 (a)	324.8 (a)	270.8 (ab)	269.0 (ab)	291.6 (a)

Field:

Seedlings in all treatments had 90 % or greater survival three seasons after planting (Table 2), except seedlings grown without fertilizer that showed a low survival of 70 %. Even the small amount of fertilizer of 1.6 mg N per seedling at the 1/2Ex treatment increased seedling survival substantially.

Seedling height three years after planting ranged from 11.3 cm at 0x to 40.8 cm at 6x (Table 2). Height was significantly greater with all fertilizer treatments than seedlings grown with water only, but high levels of fertilizer did not significantly improve height over the conventional treatment (x). Annual height increment of seedlings in year three did not differ significantly amongst fertilizer treatments, and ranged from 12.8 - 15.8 cm. Only the 1/2 Ex and 6x treatments expressed a significantly greater annual height increment than seedlings grown under a water only regime.

Seedling stem volume three years after planting increased with amount of fertilizer applied, resulting in significant increases at the higher treatments of 11 mg N/seedling or greater (Figure 2). Lowest response was for water-only seedlings at 4.1 cm^3 which was more than a 200% reduction in growth below the conven-tional x fertilization level of 8.1 mg N per seedling. By contrast, the 2x and 6x treatments increased stem volume by 43 and 58 %, respectively, over the conventional x treatment, to a maximum of 11.7 cm^3 at the 6x treatment level.

Three years after planting, fertilized seedlings in all treatments reduced to a relatively level nitrogen concentration of between 1.58 and 1.73 % (Figure 1). This is a considerable reduction from pre-plant levels that reached as high as 2.9%.

Table 2. Third year post plant growth response of seedlings. Columns followed by the same letter are not statistically different at p= 0.05.

Fertilizer level	0x	1/2Ex	1/2x	Ex	x	1.2x	1.4x	2x	6%
stem volume (cu.cm)	4.1(a)	6.4(b)	7.1(b)	7.7(c)	7.4(c)	7.7(c)	8.7(d)	10.6(d)	11.7(d)
Ht.increment (cm)	11.3	15.7	13.5	12.8	14.1	111	13.2	13.3	15.8
	(a)	(ab)	(ab)	(ab)	(ab)	(ab)	(ab)	(ab)	(b)
Helght (cm)	18.6	32.9	32.2	33.5	36.9	32.9	37.5	40.2	40.8
	(a)	(b)	(b)	(b)	(bc)	(b)	(bc)	(c)	(c)
Survival %	70	98	94	90	96	90	94	94	90

Stepwise linear regression between pre-plant seedling characteristics and stem volume three years after planting (Table 3) shows a strong positive relationship with %N (R^2 =0.84), N content (R^2 =0.72) and shoot to root ratios (R^2 = 0.85). Root weight also showed a high R^2 , at 0.75, but this is clearly inter-correlated with shoot to root ratios. Much weaker R^2 values were obtained for pre-plant seedling height, diameter, and total dry weight (Table 3).

DISCUSSION

N content of pre-plant seedlings is considered as the primary causative factor in increasing stem volume after planting (Figure 3), despite its lower R^2 value than both % N and shoot to root ratios. N content combines foliar N % multiplied by seedling total dry weight and is therefore a more robust measure of seedling N status than % N alone.

High shoot to root ratios with increasing fertilization application rates at the greenhouse are expected; as N availability increases, shoots develop preferentially over roots. This trend was also evident in Timmer and Munson (1991). Further, % N and shoot to root ratios are themselves highly inter-related at the greenhouse (R^2 =0.87). Salonius and Beaton (1994) discovered that three years after planting, seedling shoot to root ratios converged to a common value on the same site. Therefore, shoot to root ratios are considered an expression of

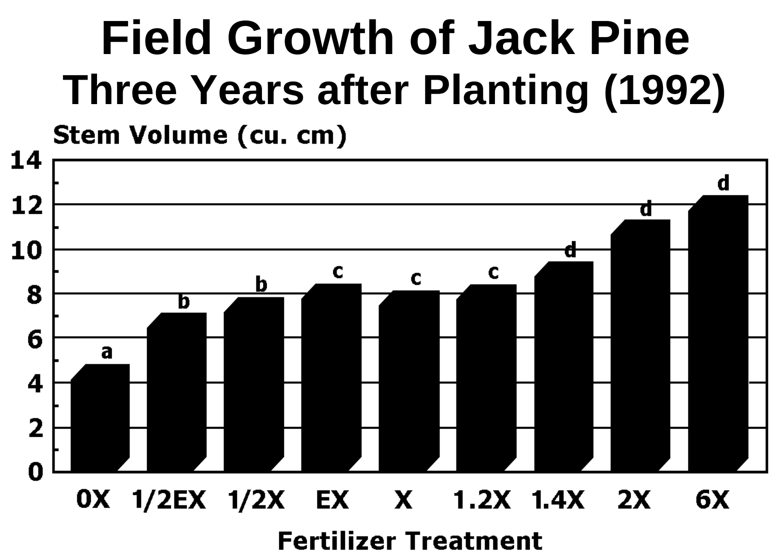

Figure 2

Table 3. Coefficient of determination (R^2) of pre-plant seedling characteristics with third year post plant stem volume.

%N	N content	shoot root	height	diameter	height diameter	root weight	shoot weight	total weight
0.84	0.72	0.85	0.58	0.61	0.56	0.75	0.44	0.33

cultural practices at the greenhouse only and are not a reliable predictor of field performance.

The result of this study agrees with earlier reports (e.g.Timmer and Munson 1991) which also relates high pre-plant N to improving out plant performance. Greatest enhanced growth occurred in seedlings that received more than 11 mg N at the greenhouse, or between 40-600% more N than conventionally applied. The wide range of increased N rates is indicative of the plasticity of jack pine in accommodating fertilizer with-out adverse effects. The highest regime, at 48 mg N/seedling, however, did not significantly improve seedling out plant volume over the lower application rates of 11-16 mg N/seedling. Further, shoot to root ratios were dangerously high (7:2).

For jack pine, therefore, we have identified the optimum luxury consumption level of applied nitrogen at the greenhouse to be 11-16 mg N/seedling, based on morphology at the greenhouse and then superior response in the field. This nitrogen amount is higher than reported values by Columbo and Smith (1988) and Timmer and Armstrong (1987) for red pine, although these studies evaluated crop response at the greenhouse only. Our N percentage values were also higher - at 2.4-2.9 - however, budgetary restrictions prevented large collections that would provide more accurate windows of %N and N-content values.

Timmer et al. (1991) suggests that exponential feed programmes at the greenhouse may be optimum for developing a more physiologically acclimatized seedling and also effectively 'loads' the seedling with high N prior to planting. Our two exponential treatments may have accomplished this if trees were grown for several more weeks or, with a higher start N value

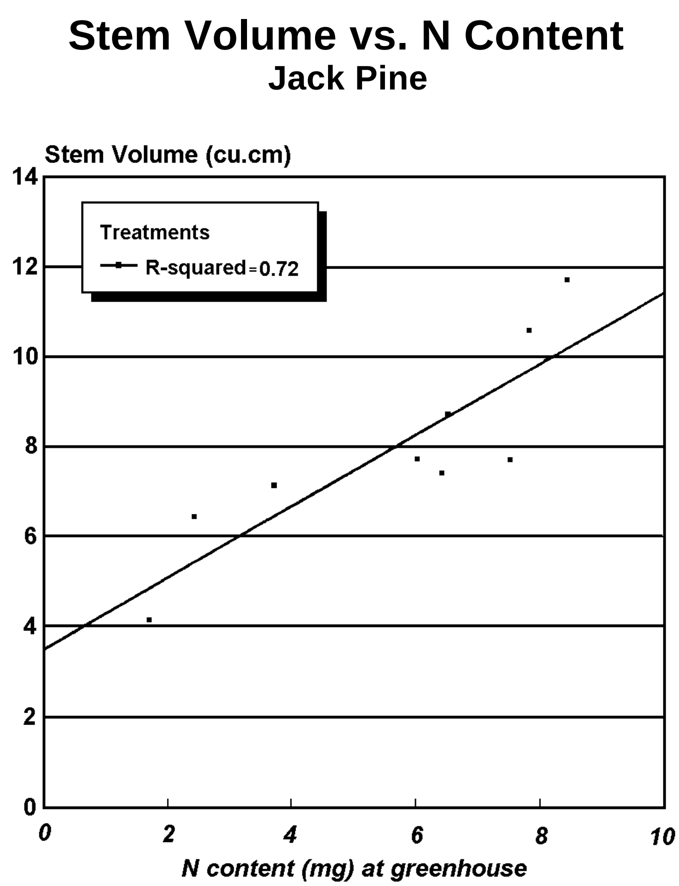

Figure 3

It is clear that high pre-plant N greatly benefitted seedling outplant performance. Timmer and Munson (1991) suggest that N is a stored nutrient reserve which can be tapped by seedlings soon after planting. Munson and Bernier (1993) recorded a rapid decline in N of black spruce seedlings in the first year after planting. And van den Driessche (1985) found that Douglas-fir seedlings lost all pre-plant N as well as P and K in the first two months after planting. The implication is that N reserves are used immediately by seedlings after planting, probably in its first year, and the reserves are shunted towards establishment and growth strategies such as new shoots and roots. This accounts for the early differences in stem volume between treatments, evident by second year measurements. The advantage of high N reserves, therefore, is conferred to seedlings as a short term burst of accelerated growth. This initial advantage given to treated seedlings then carries forward through the formative years of plantation establishment.

Another feature of high N reserves is that it benefits only the seeedling, as opposed to field fertilization which promotes growth of both desired and non-desired species. With field herbicide spraying programes phasing out due to public sensitivity, greenhouse-based techniques such as high N should become increasingly attractive. Incorporating luxury N into greenhouse programs is simple and inexpensive, especially when considering that the benefits could be 20-40% more stem volume development after only 3 years in the ground.

Finally, industry standards in North America presently place a heavy reliance on seedling morphology at the greenhouse, particularly for establishing payment contracts. It is notable that in this study, greenhouse seedling height and stem diameter contributed very little to outplant performance. Given the importance of seedling N amount in predicting field growth, however, measurement of foliar N could prove to be a most useful complementary tool for assessing stock quality.

ACKNOWLEDGMENTS

The authors are grateful for the review comments and encouragement of this study provided by R. van den Driessche, V. Timmer and S. Columbo.

REFERENCES

Anon. 1974. The system of soil classification for Canada. Publication 1455. Can. Dept. of Agriculture.

Bremner, J.M. and C.S. Mulvaney. 1982. Total nitrogen. In, Methods of soil analysis. Part 2., chemical and microbial properties. R.H. Miller, D.R. Keeney and A.L. Page,eds. Madison, Wisconsin: Am.Soc. Agron.Inc. pp.595-624.

Burgess, D. 1990. White and Black spruce seedling development using the concept of relative addition rate. Scand. J. For. Res. 5: 471-480.

Columbo, S.J. and W.A. Smith. 1988. Response of containerized black spruce and jack pine seedlings to fertilization rate and growing medium. Forestry Rep. No.116, MNR, Ont. 15 p.

Forslund, R.R.1982. A geometrical tree volume model based on the location of the centre of gravity of the bole. Can. J. For. Res. 12(2): 215-221.

Forslund, R.R. and J.M. Patterson. 1994. Nondestructive volume estimates of 11-yr-old Jack Pine and Black Spruce using the power function volume model. Submitted for publication.

Ingestaad, T. and A.B. Lund. 1979. Nitrogen stress in birch seedlings. I. Growth technique and growth. Physiol. Plant. 45:137-148.

Munson, A.D. and P.Y. Bernier. 1993. Comparing natural and planted black spruce seedlings. II. Nutrient uptake and efficiency of use. Can. J. For. Res. 23:2435-2442.

Landis, T.D. 1985. Mineral nutrition as an index of seedling quality. In, Duryea,M.L. (ed). Proceedings: Evaluating seedling quality: principles, procedures and predictive abilities of major tests. Oct.16-18,1984. Oregon State University, Corvalis.USA.

Landis, T.D., R. Tinus, S.E. MacDonald and J.P. Barnett. 1989. Seedling nutrition and Irrigation, Vol. 4, The Container tree nursery. Agric. Handbook. 674 Washington, D.C.: USDA For. Serv. 119 pp.

Salonius, P. and K. Beaton. 1994. Effect of root packing on field performance of container seedllings. Paper at: Making the Grade, IUFRO Symposium, Sault Ste. Marie, Ont. Sept. 11-15.

Scarratt, J.B. 1986. An evaluation of some commercial soluble fertilizers for culture of Jack Pine Stock. Info-Rep. 0-X-377. For. Can. Great Lakes For. Centre.

Sims, R.A., W.D. Towill, K.A. Baldwin and G.M. Wickware. 1989. Field guide to the Forest Ecosystem Classification for Northwestern Ontario. For. Can. Great Lakes Centre. Sault Ste. Marie, Ontario.

Snedcor, G.W. and W.G. Cochran. 1980. Statistical Methods. The Iowa State University Press. Ames, Iowa. USA.

Timmer, V.R. and A.D. Armstrong. 1987. Diagnosing nutritional status of containerized tree seedlings: comparitive plant analyses. Soil Sci. Am. J. 51:1082-1086.

Timmer, V.R. and A.D. Munson.1991. Site-specific growth and nutrition of planted response. Can. J. For. Res. 21:1058-1065.

Timmer, V.R., G. Armstrong and B.D.Miller. 1991. Steady-state nutrient pre-conditioning and early outplanting prformance of containerized black spruce seedlings. Can. J. For. Res. 21:585-594.

Troeng, E. and L. Aczell. 1988. Growth regulation of Scotts pine seedlings with different fertilizer composition and regimes. New Forests 2:119-130.

Van den Driessche, R. Late-season fertilization, mineral nutrient reserves, and retranslocation in planted Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) Seedlings. Forest Sci., Vol.31, No. 2:485-496.

Van den Driessche, R. 1980. Effects of nitrogen and phosporus fertilization on Douglas-fir nursery growth and survival after outplanting. Can. J. For. Res.10:65-70.