Nine Different Nursery Fertilizer Regimes Still Affecting Jack Pine Plantation Growth After 12 Years

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Introduction

The efficient use of N-fertilizer 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 the 10 fertilizer treatments applied at 100 ppm nitrogen (N) to jack pine yielded similar seedling morphology, with no apparent advantage conferred by special forestry mixes or starter and finishing preparations, despite large differences in supplied nutrients. Colombo and Smith (1988) measured greatest shoot, diameter and root dry weight in containerized jack pine which corresponded to 9.19 mg N per seedling and 1.91–2.33% foliar N. Timmer and Armstrong (1987) found that 10 mg N per 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 containerized 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 outplanting, 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 indictors 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

Nursery

Jack pine (*Pinus banksiana* Lamb.) seedlings grew in a plastic covered greenhouse at Northern Greenhouse Farms, Iroquois Falls, Ontario, and Latitude 48° 46’N, Longitude 80° 41’W. The seedlings were sown on June 26, 1989 into Jiffy Forestry Pellets type 2865-165 (Jiffy Products (NB) Ltd., Shippagan, New Brunswick) at a density of 990 pellets per m^2. Each pellet was approximately 6.5 cm in height and 3 cm in diameter (after expansion) and contained 50 cc of sphagnum peat moss amended to a pH of 4.5 and electrical conductivity of 1.0 millimhos. Jiffy pellets are covered by a mesh net that compartmentalizes individual cavities/pellets.

Seedlings developed under natural daylight. Greenhouse conditions ranged from night minimum to day maximum temperatures of 15 to 20°C.

Twenty-seven trays (1 tray = 33 pellets) were arranged on benches in a randomized block design (8,910 total seedlings) such that each of the nine fertilizer treatments was replicated three times, with one tray representing one treatment per replication.

Seedlings were fertilized using the following treatments of differing concentrations of N:

1. 0x, water only (0 ppm N); 2. ½x, (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). The “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):

$Nt = Ns (e^{rt} – 1)$
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 ½ 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) 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 (Snedecor and Cochran 1980).

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

After measurements, seedlings were moved in trays to an outside holding area in the same design pattern as in the greenhouse to harden and over winter 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 in the Upper Spanish Forest, Latitude 47° 28’ N, and Longitude 81° 50’ W.

The site is a level, glaciofluvial outwash plain, characterized by deep, rapidly drained course 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 were planted, for a total of 450 seedlings.

Seedlings were measured in 1993 and again in 2002 for total height and diameter at one-third of stem height. Stem volumes were estimated using the formula for a cone as follows (Vol (cc) = (πR^2 X HT)/3). Data was examined by one-way ANOVA and Least Significant Difference tests to determine treatment effects.

Results

Nursery

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 nursery 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 the 1/2Ex treatments, delivering 0 and 1.6 mg N/ 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.

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 (Fig. 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

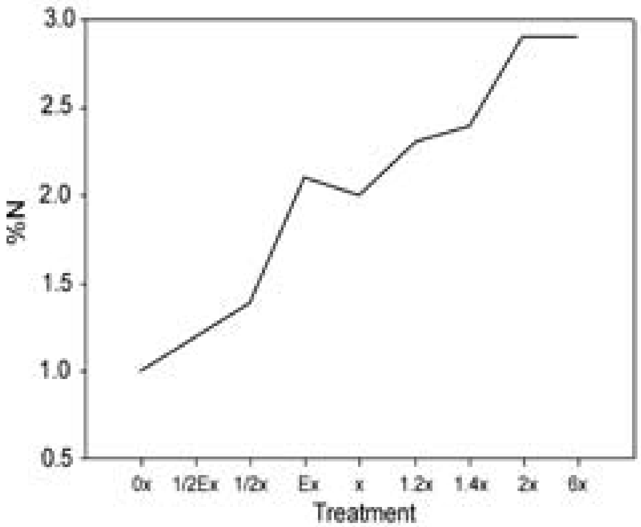

Figure 1. *Foliar N concentrations in needles according to fertilization treatment.*

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 (Fig. 2). Toxic growth response to high N was not observed and is therefore above 48 mg N per seedling.

Table 1. *Amount of N applied by treatment and response of jack pine seedlings at greenhouse rotation end. Values within a row 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	6x
N applied (mg/seedling)	0	1.6	4.1	5.9	8.1	9.7	11.4	16.2	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	6.5	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 (c)	1.1 (bc)	1.3 (ab)	1.4 (ab)	1.4 (ab)	1.5 (a)	1.4 (ab)	1.4 (ab)	1.5 (ab)
Ht:diameter ratio	52.5	66.0	78.8	78.1	79.7	82.9	79.9	82.3	80.1
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 ratio	2.1 (e)	2.4 (d)	4.0 (cd)	4.2 (bc)	4.9 (bc)	5.3 (bc)	6.1 (bc)	6.7 (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 survival substantially. After 12 years the survival trend is similar with very little loss between the 3rd and 12th year.

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).

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 (Fig. 2). Lowest response was for water-only seedlings at 4.1 cm^3 which was more than a 200% reduction in growth below the conventional 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 cm3 at the 6x treatment level. In 2002, stem volumes are over 500 times larger than in 1993, but the trend is similar. Although seedlings that were not fertilized in the greenhouse are smaller, the differences between these and seedlings that received up to 11.4 mg per seedling are not significant. The 2x and 6x treated seedlings are now 45% and 64% larger, respectively, than the conventional x treatment.

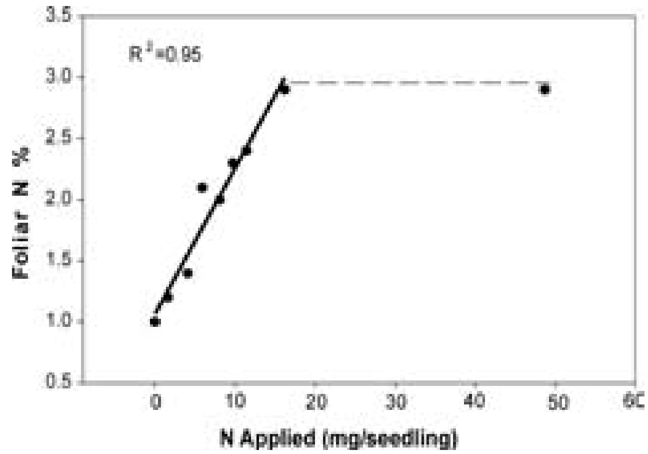

Figure 2. *Relationship between the amount of N applied to a crop and the resulting foliar N level.*

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

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). Again, the trend is similar after 12 years (Figs. 3 and 4).

Table 2.
Values within a row 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	6x
Stem volume (cm^3)	1993	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)
	2002	2938 (a)	3470 (ab)	3095 (a)	3517 (ab)	3605 (ab)	3309 (a)	3807 (ab)	5234 (bc)	5927 (c)
Height (cm)	1993	18.6 (a)	32.9 (b)	32.2 (b)	33.5 (b)	36.9 (bc)	32.9 (b)	37.5 (bc)	40.2 (c)	40.8 (c)
	2002	356 (a)	350 (a)	338 (a)	361 (a)	341 (a)	333 (a)	363 (a)	388 (a)	396 (a)
Survival (%)	1993	70	98	94	90	96	90	94	94	90
	2002	70	96	90	88	96	86	94	88	88

Table 3. *Coefficient of determination (R^2) of pre-plant seedling characteristics with third year (1993) and twelfth year (2002) post plant jack pine stem volumes.*

Year	%N	N Content	Shoot: Root	Height	Diameter	Height: Diameter	Root Weight	Shoot Weight	Total Weight
1993	0.84	0.72	0.85	0.58	0.61	0.56	0.75	0.44	0.33
2002	0.89	0.72	0.81	0.24	0.30	0.18	0.93	0.18	0.23

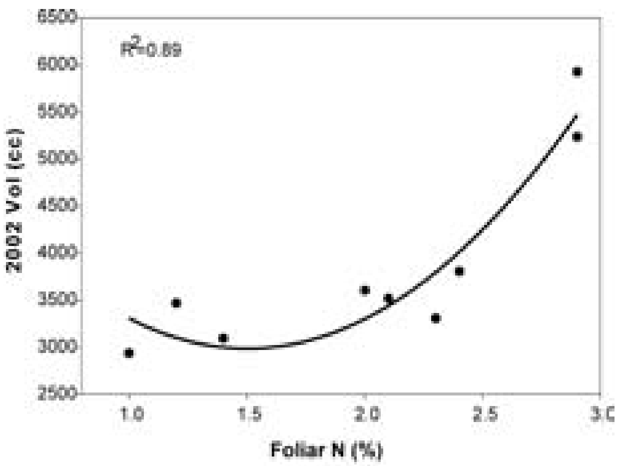

Figure 3. *Relationship between foliar N level at the greenhouse and stem volume after 12 years in the plantation.*

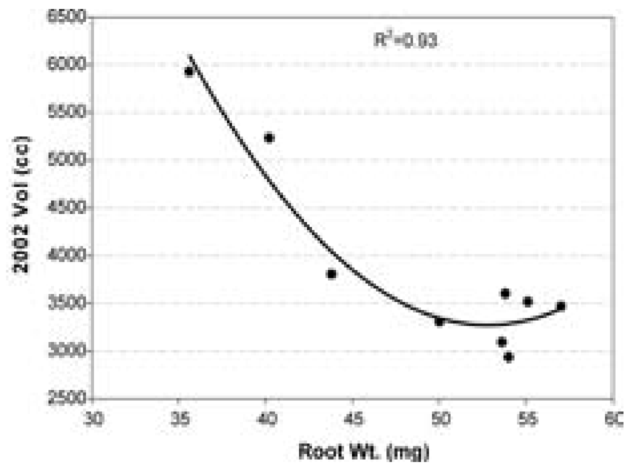

Figure 4. *Relationship between root weight after the nursery phase and stem volume after 12 years in the plantation.*

The negative correlation between root weight at time of planting and tree size after 12 years (Fig. 3) is unusual, since it means that, in this case, jack pine seedlings with smaller root systems grew faster in the plantation. As is implied in Figs. 3 and 4, the seedlings with the smaller root systems also had the highest foliar N concentration (2.9%)

Discussion

High shoot/root ratios (or low root weights) are not generally considered to be positive traits in terms of planting stock quality. However, smaller root systems in seedlings that have been heavily fertilized throughout the nursery phase are expected. At high soil fertility levels, seedlings will develop shoots preferentially over roots. This trend was also reported by Timmer and Munson (1991). In addition, 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 probably expressions of cultural practices at the nursery and are not reliable indicators of field performance. The fact that the seedlings with the higher foliar N levels performed the best in the field probably outweighed any possible negative effect of initial small root systems.

It is also possible that the smaller root systems were less damaged due to container separation at planting time. There may have been fewer interconnecting roots in trays grown at higher nitrogen rates, meaning there would be fewer roots severed when seedlings were separated for planting. Even with smaller root systems, the fabric encasing the Jiffy plug held the soil and root together to allow planting. The ability to plant container seedlings having less developed root systems is an advantage only Jiffy containers have. The timing of pruning interconnecting roots in Jiffy's is an important cultural practice that needs further study.

This study relates high pre-plant nitrogen to improved field performance. The greatest enhanced growth occurred in seedlings that received 16 mg and 49 mg at the greenhouse. Conventional fertilizer schedules at that time (1990) tended to apply a total of about 10 mg per seedling. Seedlings that received 49 mg did not perform better than seedlings that received 16 mg. This suggests that conventional fertilizer schedules should target about 16 mg per seedling to avoid wasting fertilizer while maintaining healthy foliar nutrient levels. However, there are likely other application methods to ensure optimum foliar nutrient levels at time of planting.

Timmer et al. (1991) suggest that exponential feed programs at the greenhouse may be optimum for developing a more physiologically acclimatized seedling and also effectively 'load' the seedling with nitrogen prior to planting. Our two exponential treatments may have accomplished this if trees were grown for several weeks more or if the schedule started with a higher nitrogen level.

Nutrient 'spiking' is a practice of providing high levels of fertilizer to the container soil just prior to planting. Timmer and Teng (2004) found that by soaking the soil plug with fertilizer prior to planting to increase soil fertility and plant nutrient status, plant biomass and nitrogen levels were increased by 81% and 156%, respectively, one year after outplanting.

It is clear that high pre-plant nitrogen improved 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 in the first year after planting. van den Driessche (1985) found that Douglas-fir seedlings lost all pre-plant nitrogen in the first two months after planting. The advantage of high nitrogen 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. This study indicates that this advantage is evident 12 years after planting.

Another feature of high nitrogen reserves is that it benefits only the seedling, and not the surrounding competing vegetation. When considering the high cost of plantation tending programs, greenhouse based techniques such as targeting high nitrogen content should become increasingly attractive, and seedlings that perform better in the field should be worth more.

Finally, industry standards in North America presently rely on seedling morphology after the nursery phase as a measure of acceptable planting stock. It is notable that within the range of size in this study, greenhouse seedling height and diameter did not relate to outplant performance. Perhaps foliar nutrient status could prove to be a useful tool for assessing planting stock quality.

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