New Forests 2: 119—130 (1988)

Growth regulation of Scots pine seedlings with different fertilizer compositions and regimes

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Received 3 January 1987; accepted 15 February 1988

Key words: Pinus sylvestris, fertilization, nitrogen, potassium, phosphorus, outplanting performance

Application. Fertilizer regime can be used to regulate seedling growth precisely, in the laboratory. However, for containerized Scots pine seedlings grown in peat, little difference in nursery growth and outplanting performance was found with fertilizers of different composition. Regulation of seedling growth was only weakly controlled by the fertilizer regime.

Abstract. Scots pine (Pinus sylvestris L.) seedlings were grown in containers filled with peat, using two different fertilizers and three different fertilizer regimes. Seedling shoot and root growth and shoot content of nitrogen, potassium and phosphorus were followed in the nursery and after outplanting in the field. Attempts to regulate growth rate by an exponential nutrient supply were not successful, but the root/shoot ratio was influenced by the fertilization regime. Internal nitrogen concentration was stable only for seedlings with low relative growth rate, while seedlings with high nutrient supply in the nursery showed strong nutrient dilution in the shoot after planting.

Introduction

Nutritional schedules for growing tree seedlings have been an area of much research. Brix and van den Driessche (1974) have reviewed the subject regarding nursery growth of tree seedlings in containers.

Different nutritional compositions have been described which are considered suitable for all stages of seedling growth (Hoagland and Arnon 1938; Epstein 1972; Ingestad 1979). Results from research concerned with the individual effect of nitrogen, potassium and phosphorus (cf. Mitchell 1939; Brix and van den Driessche 1974; Salisbury and Ross 1978) indicate that it could be more efficient to change the nutritional composition and provide the seedlings with a higher content of phosphorus in the early stages (2—3 weeks after sowing) and a higher content of potassium at bud set. Ingestad

(1977, 1982) has shown in laboratory experiments under controlled environmental conditions and in water culture that it is possible to regulate seedling growth by supplying nutrients at a relative addition rate. By adding nutrients exponentially at a predetermined rate it is possible to keep the nitrogen concentration in the seedlings constant. The growth will then follow a desired rate during the exponential growth phase.

The aim of this study was to find out the effects on seedling growth comparing constant nutrient proportions with a nutrient solution where the nutrient composition varied during different periods of seedling growth. Regulation of seedling growth rate with different fertilizer regimes, when using peat substrate, was also investigated.

Materials and methods

The plant material consisted of first year seedlings of Scots pine (*Pinus sylvestris* L.). Seeds were collected from a seed orchard located at Hedesunda (60°20′N, 17°05′E, altitude 60 m) containing grafted trees originating from latitudes between 58°03′ and 61°37′N and altitudes between 70 and 170 m. Sowing took place on February 21 in plastic containers (Panth AB, Sweden) with 664 seedlings per square meter and a container volume of 92 cm^3. The substrate used was sphagnum peat (Hasselfors K11, Sweden) containing 2 kg of dolomite lime per cubic meter. The seeds were germinated and grown at 22 °C in a plastic greenhouse chamber at the Swedish University of Agricultural Sciences, Garpenberg (60°17′N, 16°12′E). Additional light was supplied by 400 W high pressure sodium lamps providing 90—120 μmol $m^{-2}\,s^{-1}$, giving a daylength of 18 h.

The seedlings were watered daily while fertilization took place twice a week. Three different fertilizer regimes were used. One nutritional regime was a constant supply of 4 g N m^{-2} $week^{-1}$ to provide a nutrient surplus, while the other two regimes were based on a desired plant growth of 3.5% and 7% RGR (relative growth rate) respectively (cf. Ingestad and Lund 1979).

RGR is defined by the formula

$$\mathrm{RGR}\ (\%) = \ln \frac{(w_2)}{(w_1)} \cdot \frac{100}{(t_2 - t_1)}$$

where w_1 = seedling weight at day t_1; w_2 = seedling weight at day t_2.

Amount of nitrogen addition to provide relative growth rates of 3.5% and 7% was calculated from seedling dry weight and a theoretically assumed nitrogen content of 2.5% of dry weight (cf. Ingestad and Lund 1979).

Two different fertilizers were used: Wallco (Mölnlycke AB, Sweden) and Peters (Peters Fertilizer Products, USA). Wallco has a N:K:P ratio of 100:65:13. Peters consists of three different solutions: "Starter" (N:K:P = 7:14:17), "Grower" (N:K:P = 20:16:3) and "Finisher" (N:K:P = 4:29:11). The compositions of the fertilizers are given in Table 1.

The concentrated fertilizer was diluted by water before being supplied, and after fertilization the seedlings were rinsed with water. When comparing Peters and Wallco, equal amounts of nitrogen were added. Fertilization started 12 days after sowing. Between days 12 and 35 after sowing 2 g N per square meter and week was supplied using Wallco and Peters "Starter", respectively. 35 days after sowing, at the start of the relative nutrient addition regime, peat was leached with water until the conductivity measured with YSI model 33 (YSI Co, USA) was equal to that of water, and then the different nutrient regimes were applied. When budsetting was initiated, 77 days after sowing, Peters "Finisher" was given instead of "Grower". On day 91 seedlings were moved outside. The seedlings were outplanted 124 days after sowing (June 25) in three randomized blocks with 30 seedlings in each block. The planting site was a cultivated but unfertilized sandy plain situated 60°15′N, 16°01′E at an altitude of 110 m. 250 days after sowing (October 29) shoot dry weight, height and survival were determined.

When substrate conductivity was determined, the peat was saturated with water and after one hour 20 ml of liquid was pressed out of the container and measured (cf. Lukas and others 1972; Timmer and Parton 1984).

The dry weight (80 °C, 48 h) of shoots and roots was determined on five occasions. Shoots were then chemically analysed to determine N, K and P concentration as percentage of dry weight. Nitrogen was determined by a micro-Kjeldahl procedure while potassium and phosphorus were determined by atomic absorption spectrophotometry. All N, K and P values are mean values from two samples, which seldom differed by more than 5%.

At each sampling occasion 10 seedlings from each of three randomized blocks were collected, edge seedlings being avoided. Statistical analysis were made by Anova and significant differences in dry weight between treatment means were established by F-test ($p = 0.05$).

Results

Dry weight development of the shoot was clearly influenced by the fertilizer regime so that a higher nitrogen supply increased shoot dry weight. Differences in shoot dry weight were found when different nutrient regimes had been applied for two weeks. For seedlings fertilized with Wallco in the nursery, the highest nitrogen supply also gave the highest growth after planting (Fig. 1a). This was not the case for seedlings fertilized with Peters where seedlings given a constant weekly supply in the nursery showed a lower shoot growth after planting than expected (Fig. 1b).

Seedlings fertilized with Wallco in the nursery developed side branches after planting much more frequently than seedlings fertilized with Peters where branching were rare during growth after planting. The large standard deviation of shoot growth after planting for Wallco fertilized seedlings (Fig. 1a) was an effect of individual variation. About half of these seedlings developed side branches which increased shoot weight considerably compared to non-branched seedlings.

Dry weight development of the root was also significantly influenced by the fertilizer regime but not by the composition of the nutrient solution applied. Low nitrogen supply increased root growth so that the 3.5% RGR

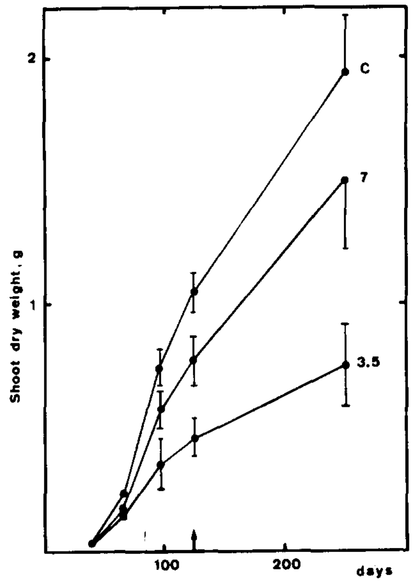

Fig. 1a. Shoot growth in the nursery and after planting for seedlings fertilized with Wallco fertilizer. The arrow indicates planting day.

C = Constant supply, 4 g N m^{-2} $week^{-1}$, totally 37 g N m^{-2}.

7 = Exponential supply according to RGR = 7%, totally 23 g N m^{-2}.

3.5 = Exponential supply according to RGR = 3.5%, totally 13 g N m^{-2}.

Vertical bars show standard deviation.

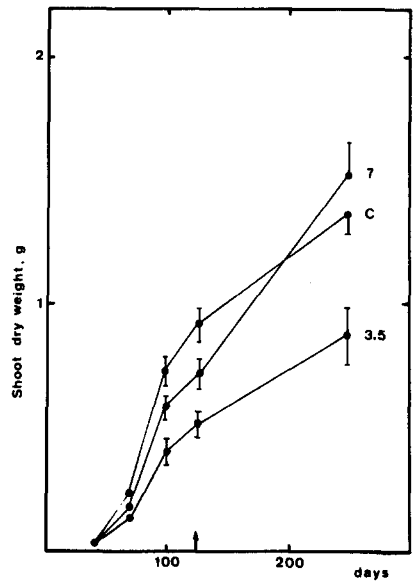

Fig. 1b. Shoot growth in the nursery and after planting for seedlings fertilized with Peters fertilizer. The arrow indicates planting day.

C = Constant supply, 4 g N m^{-2} $week^{-1}$, totally 37 g N m^{-2}.

7 = Exponential supply according to RGR = 7%, totally 23 g N m^{-2}.

3.5 = Exponential supply according to RGR = 3.5%, totally 13 g N m^{-2}.

Vertical bars show standard deviation.

Table 1. Compositions of different nutrient solutions expressed as percent.

	Wallco	Peters "Starter"	Peters "Grower"	Peters "Finisher"
N (total)	8.3	7.0	20.0	4.0
NH_4—N	3.8	3.4	7.0	1.0
NO_3—N	4.5	3.4	11.6	—
urea	—	0.2	1.4	3.0
K	5.5	14.1	15.7	29.0
P	1.1	17.4	3.1	10.9
S	0.8	0.2	0.4	1.9
Mg	—	0.15	0.3	0.3
Fe	0.026	0.2	0.4	0.4
Mn	0.008	0.03	0.06	0.06
B	0.010	0.015	0.025	0.025
Zn	0.012	0.03	0.06	0.06
Cu	0.005	0.03	0.06	0.06
Mo	0.007	0.003	0.005	0.005

Table 2. Relation between fertilizer regime, total nitrogen supply, root biomass and root/shoot ratio after 91 days in the nursery.

Fertilizer regime	Total amount of nitrogen added ($g\ m^{-2}$)	Root biomass (mg $seedling^{-1}$)	Root/shoot ratio
Wallco 4gN m^{-2} $week^{-1}$	37.4	113	0.16
Wallco RGR 7%	23.6	144	0.28
Wallco RGR 3.5%	13.3	159	0.52
Peters 4gN m^{-2} $week^{-1}$	37.4	112	0.16
Peters RGR 7%	23.5	135	0.26
Peters RGR 3.5%	13.8	158	0.48

regimes had 40% more root dry weight than seedlings fertilized with 4 g N m^{-2} $week^{-1}$ when fertilization ceased (Fig. 2). This also influenced the root/shoot ratio, giving highest values when nitrogen supply was low (Table 2).

The desire to regulate growth to a certain relative growth rate and ultimately to a final seedling size with fertilization regime and nutrient composition was not successful. Relative growth rate was initially low, reached a maximum between 21 and 28 days after sowing and decreased during the following periods (Fig. 3). The pattern was similar for shoots and roots, even if root growth initially was lower and reached a higher maximum. There was no significant difference in growth rate for different exponential fertilization regimes, thus indicating that factors other than nutrient supply had a main influence on growth regulation. However, low nitrogen supply promoted growth rate of the root system while high nitrogen supply improved shoot growth rate.

Shoot N concentration (%) was initially high but decreased with time for all nutrient regimes. At the time of outplanting, shoot nitrogen content was about 2% except for the 3.5% RGR regimes where nitrogen content was lower (Fig. 4). After planting the nitrogen content decreased further except for the Wallco RGR 3.5% which was constant at 1.50% from 68 days after sowing to the end of October. Nitrogen concentration of shoots fluctuated more for the Peters regimes. There was a clear increase in nitrogen concentration of the shoot when the "Finisher" was supplied to the 3.5 and 7% RGR regimes (Fig. 4).

Potassium and phosphorus concentration of the shoot generally decreased with time (Fig. 4), except that Peters "Finisher" gave an increase in phosphorous and potassium shoot concentration when applied. For Wallco no such increase was found. The high proportion of phosphorus of the Peters "Starter" solution had no effect on root growth or shoot concentration of phosphorus.

The potassium concentration of the shoot decreased about 50% from outplanting to the end of the vegetation season for seedlings earlier fertilized with 4 g N m^{-2} $week^{-1}$. Potassium decrease was smaller for Wallco RGR 7% and Wallco RGR 3.5%. This was a dilution effect due to greater growth of seedlings with constant weekly supply.

The only fertilization regime where internal nitrogen concentration remained stable was the Wallco RGR 3.5%. Nitrogen status of the shoot remained constant also after outplanting. Phosphorus content increased after planting while potassium content decreased, but not as much as in other fertilization regimes. No differences in survival between the different fertilization regimes were found at the end of the season.

Discussion

Different fertilizer compositions caused little or no effect on shoot or root growth in the nursery. This was also found by Scarratt (1986) in a similar experiment with jack pine. Instead, the amount of nitrogen supplied determined the size and dry matter development of the seedlings. When nitrogen status decreased as a result of low nitrogen supply, root growth was favoured at the expense of growth of needles and stem (cf. Ingestad 1977). Consequently, the 3.5% RGR nutrient regimes had the highest root biomass in the nursery (Fig. 2). If this root biomass is active this will facilitate seedling establishment and survival after planting. In this study, only small differences in field performance between treatments were found. However, in case of water stress and on a site with more restricted supply of nutrients, large seedlings with a low root/shoot ratio would probably show lower survival and restricted growth after planting (Burdett and others 1984).

The failure in this study to regulate growth rate in the nursery to the desired level was probably caused by several reasons. Fertilization twice a week meant that nutrients were not continously supplied. Even if nutrients were supplied at an exponentially increasing rate, (RGR 3.5% and RGR 7%) microorganisms in the peat were competing for the nutrients added. Also the

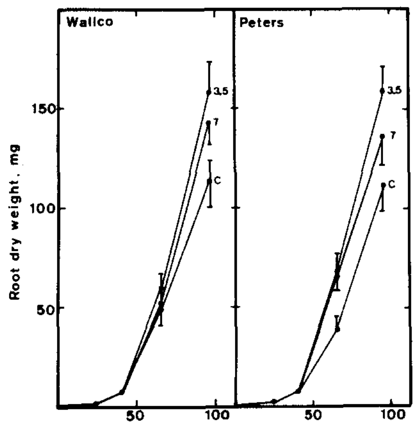

Fig 2. Root growth in the nursery for seedlings fertilized with Wallco and Peters fertilizers.

C = Constant supply, 4 g N m^{-2} $week^{-1}$, totally 37 g N m^{-2}.

7 = Supply according to RGR = 7%, totally 23 g N m^{-2}.

3.5 = Supply according to RGR = 3.5%, totally 13 g N m^{-2}.

Vertical bars show standard deviation.

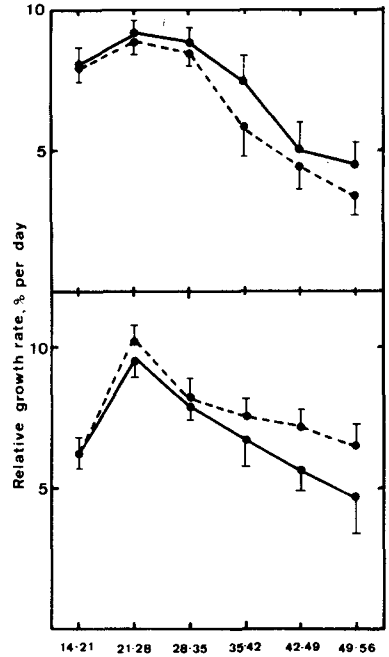

Fig. 3. Average relative growth rates for shoot (above) and root (below) for different periods after sowing for seedlings fertilized with Wallco.

Solid line = Fertilization supply according to RGR = 7%.

Dotted line = Fertilization according to RGR = 3.5%.

Vertical bars show standard deviation.

restricted volume for root development and mutual shading of needles decreased the calculated maximal growth rate. Finally, at bud set relative growth rate decreased and did not follow the exponential growth curve.

The low root uptake of phosphorus from the Peters "Starter" solution was probably due to low root biomass and growth rate during that period of

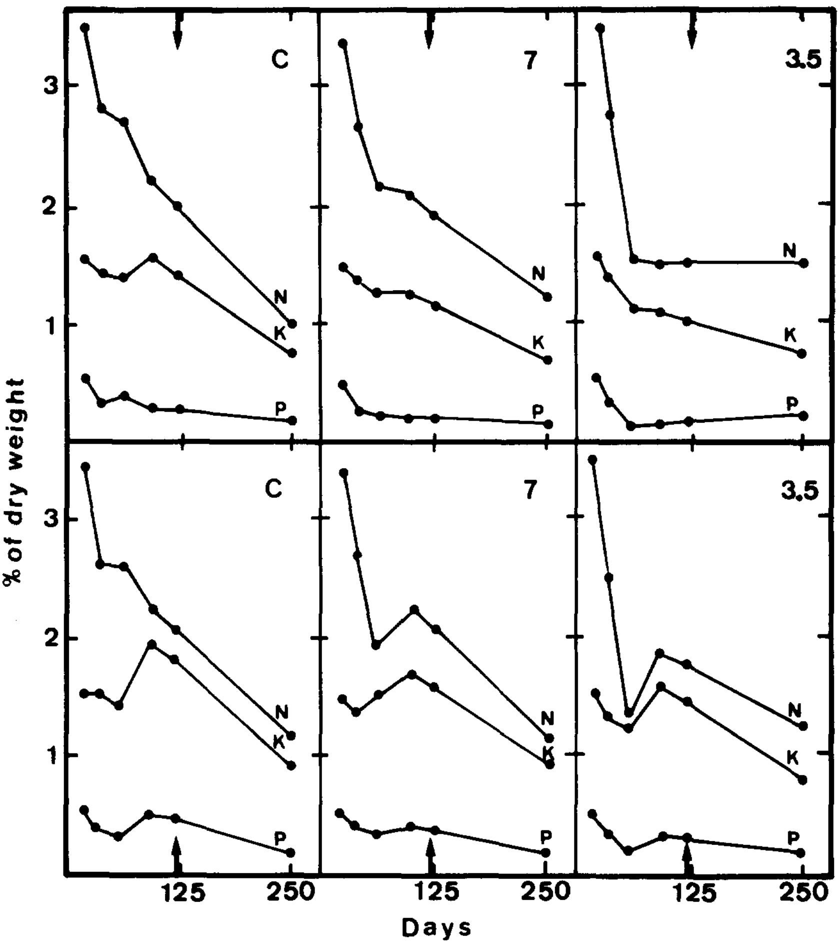

Fig. 4. Shoot concentration as percent of dry weight of nitrogen, potassium and phosphorus in the nursery and after planting.
Upper diagrams: Seedlings fertilized with Wallco.
Lower diagrams: Seedlings fertilized with Peters.
C = Constant supply 4 g N m^{-2} $week^{-1}$, totally 37 g N m^{-2}.
7 = Exponential supply according to RGR 7%, totally 23 g N m^{-2}.
3.5 = Exponential supply according to RGR 3.5%, totally 13 g N m^{-2}.
The arrows indicate planting day. Each point was based on 30 seedlings.

seedling development (Fig. 3). On the other hand, the increased phosphorus content of seedlings fertilized with the Peters "Finisher" (Fig. 4) was probably an effect of high uptake efficiency for phosphorus, leading to luxury consumption (van den Burg 1971). Mitchell (1939) found that addition of phosphorus increased root growth, especially when nitrogen supply was low. No such effect was found in this investigation.

In some investigations, little relationship between fertilization in the nursery and survival and growth after outplanting has been found (Benzian and others 1974; Mullin and Bowdery 1977) although other studies have given a positive correlation (Smith and others 1966; van den Driessche 1980, 1982). These different observations may to some extent be due to different water and nutrient stress after planting (cf. Ritchie 1984).

In this study seedlings fertilized with 4 g N m^{-2} $week^{-1}$ and with 7% RGR showed a marked decreased of internal nitrogen status after planting. This might cause deficiency symptoms and reduced growth rate (Ingestad and Kähr 1985).

The total amount of nitrogen in the shoot at the end of October was almost the same as at planting for seedlings fertilized with 4 g N m^{-2} $week^{-1}$ (Table 3) indicating a strong nutrient dilution in the shoot. This was probably caused by two things: uptake of nitrogen and transport to the growing shoot was very low, and redistribution of shoot nitrogen to the root system took place (cf. van den Driessche 1984). In both cases nitrogen status of the shoot will decrease and root growth will be favoured.

Fertilizer regimes of RGR 3.5% and RGR 7% showed a slight increase of total amount of nitrogen in the shoot, thus indicating a lower level of nitrogen stress than for seedlings with constant weekly nitrogen supply (Table 3).

Table 3. Shoot dry weight and nitrogen content at outplanting (day 124) and after field growth (day 250) for seedlings from different fertilizer regimes. Standard deviation intervals given.

	Day 124		Day 250	
	Shoot dry weight	Shoot N content	Shoot dry weight	Shoot N content
Fertilizer regime	(mg)	(mg)	(mg)	(mg)
Wallco 4gN m^{-2} $week^{-1}$	1050 ± 61	21.1 ± 2.4	1941 ± 204	21.3 ± 4.4
Wallco RGR 7%	778 ± 72	15.0 ± 2.8	1505 ± 251	19.1 ± 6.5
Wallco RGR 3.5%	465 ± 49	7.1 ± 1.4	752 ± 158	11.4 ± 4.7
Peters 4gN m^{-2} $week^{-1}$	920 ± 68	19.5 ± 2.8	1366 ± 72	16.0 ± 1.6
Peters RGR 7%	718 ± 64	15.4 ± 2.7	1522 ± 96	18.1 ± 2.2
Peters RGR 3.5%	522 ± 40	9.8 ± 1.5	880 ± 90	11.5 ± 1.2

The clear decrease in relative growth rate of Peters 4 g m^{-2} $week^{-1}$ after planting (Fig. 1) might indicate nitrogen stress, but also unfavourable balance between macronutrients of the "Finisher" solution (Table 1). Stable internal concentration of all nutrients are considered favourable for growth and is in good agreement with natural conditions (Ingestad and Lund 1979).

Burdett and others (1984) studying seedling establishment supported the idea that a seedling should be physiologically preadapted to the planting site as for uptake of water and mineral nutrients. The aim would be to keep the same internal nutrient status of seedlings before and after planting (cf. Nambiar and Zed 1980). Survival and growth might be reduced by differences in nutrient status of seedlings in relation to nutrients available at the planting site. This topic has been much discussed (e.g. Mullin and Bowdery 1977; Iverson 1984) but not much investigated.

In this study, only a slight indication (Fig. 1) of unfavorable growth after planting for one of the fertilization regimes (Peters 4 g N m^{-2} $week^{-1}$) supported this theory. However, the results might have been more obvious if there had been a strong stress after planting.

Conclusions

In this study, no increased root growth was found when extra phosphorus was supplied during early growth in the nursery. Increased potassium supply at bud set had no impact on outplanting performance compared to seedlings supplied with constant proportions of nutrients throughout the growth period.

It was not possible to regulate growth in detail by the amounts of nitrogen supplied, but the fertilization regime clearly influenced the root/shoot ratio.

Internal nitrogen concentration before and after planting was stable only for seedlings with low nitrogen content and low relative growth rate.

The relation between nutrients available at the planting site and nutrient status of the seedling at outplanting was not studied in detail. However, there were indications that large seedlings with high nitrogen concentration and low root/shoot ratio might show unfavourable growth and strong dilution of nutrients after planting.

Acknowledgements

We would like to thank Anders Mattsson and Anders Lindström for valuable comments on this manuscript and Britt-Marie Gabrielsson, who patiently typed the many drafts of the manuscript.

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