

## ARTICLES

# Nitrogen productivity in seven open pollinated families of *Pinus sylvestris* L.

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An approximate method for determining nitrogen productivity (biomass increase per unit nitrogen and day) in *Pinus sylvestris* L. seedlings used in a previous experiment was compared with a more rigorous method requiring a larger number of plants and repeated destructive sampling. Seedlings of seven open-pollinated (OP) families of contrasting nitrogen productivity calculated by the approximate method, were cultivated in a growth chamber for two growth periods (GPs) accomplished in 43 weeks. Heights were recorded monthly during GP1 and weekly or twice a week during GP2. Five harvests were performed during GP2 in order to estimate N productivity in a physiologically more rigorous way. Dry weights of different seedling parts and N concentrations in the needles were determined after each harvest and based on these characters, the N productivities and N utilization were computed. A poor agreement between the rhythm of height and biomass growth was found. The comparison of the same traits between the experiments shows with few exceptions higher values for the previous experiment. The approximate N productivity of the previous experiment was only weakly correlated with the N productivities of the present experiment, indicating that the approximate estimate of N productivity was not good enough to substitute for the physiologically more rigorous estimate. However, a good correlation between the N utilizations of the both experiments was found which suggests possible use of this trait for further studies.

**Key words:** Growth chamber, nitrogen productivity, nitrogen utilization, OP families, *Pinus sylvestris*, plant dry weight, Scots pine.

## Introduction

There are implications that nitrogen is one among the most limiting factors of the growth in Swedish forests (Tamm, 1991). Considering the large variation in fertility of sites where *Pinus sylvestris* grows (Hägglund and Svesson, 1982) there might be genetic differences in nutrient use (nitrogen) efficiency. In the literature nutrient use efficiency and its components have been used with different meanings. Our definitions of the terms are given below.

*Nutrient use efficiency* = a plant's ability to produce biomass in relation to available nutrients, whether it can be attributed to uptake of nutrients from a substrate or to utilization of nutrients.

*Nutrient acquisition capacity* = the amount of nutrient taken up by a genetic entry under defined non-optimal conditions in relation to uptake under conditions of free access to nutrients.

*Nutrient productivity* = total dry weight produced per unit nutrient in the needles per unit time (cf. Ingestad, 1979).

*Nutrient recycling* = the ability to transfer nutrients from low-productive sites to high-productive sites in a seedling/tree (cf. Millard, 1996).

*Nutrient utilization* = total dry weight produced per unit nutrient in the needles.

For each nutrient element a separate acquisition capacity, productivity, recycling, and utilization may be estimated.

Many reports on forest trees (Walker and Hatcher, 1965, Pritchett and Goddard, 1967, Jahromi et al., 1976, Roberds et al., 1976, Waxler and van Buijtenen, 1981, Sheppard and Cannell, 1985) indicate that genetic differences exist in nutrient use efficiency. These observations in combination with the existing variation in *Pinus sylvestris* stand site fertilities call for genetic studies of variation in N use efficiency in this species. Of particular interest would be to identify genetic entries that grow well under limiting availability of nitrogen, i.e. that have high N productivity or N utilization.

There are no studies known to us of genetic variation in N productivity in tree species using the original concept of N productivity (Ingestad, 1979). In accordance with this concept plant materials are studied during the exponential growth phase of the first growth period and under conditions when the nitrogen status and the relative growth rate of the seedlings do not change over time. Their stability can be tested by repeated harvests and analyses (cf. Ingestad, 1979) as the few genetic entries involved allow large number of plants per entry to be examined.

In our genetic studies, both duration of experiments and the number of genetic entries and individuals within entries increase considerably. The volume of material studied in genetic tests carried out with a physiologically correct approach would be too large to handle. Instead, a two-step strategy may be used in which an approximate N productivity for many families is estimated by means of simplified methods in the first step. The physiologically correct approach with destructive sampling on several occasions and assessment of "true" N productivity in representatively selected families is then carried out in the second step and the agreement between the two estimates is tested.

In a previous study (Jonsson et al., 1997) and in accordance with this two-step strategy the N productivity of 21 open pollinated families of *P. sylvestris* was estimated by an approximate method. This was done by using height growth measurements, instead of repeated harvests (during the phase of the most rapid growth), as an indirect means to determine the daily

weight increment. Harvest and tissue nitrogen analysis were carried out at the end of the second growth period. We preferred to include the second growth period in our study since the first period is different from the second and all consecutive growth periods in not having predetermined growth.

The aim of this study was to test whether the approximate estimates of nitrogen productivity calculated per day (Jonsson et al., 1997), which are feasible for genetic studies, agree with physiologically more rigorous estimates of nitrogen productivity. Similarly, estimates of N utilization from the previous and the present study will be compared.

## Abbreviations

DURGP2 – period of most intensive height growth (from 10% to 90% of the increment during GP2 only).

GP1 – first growth period.

GP2 – second growth period.

N – nitrogen

OP – open-pollinated.

## Materials and methods

### *Cultivation technique*

Seven open-pollinated families of *Pinus sylvestris* representing the range of approximately estimated N productivity (Jonsson et al. 1997) were included in this growth chamber experiment. Seed sowing was carried out in pots with a mixture of sand, perlite, and vermiculite and covered with plastic bags. After two weeks the seedlings were transplanted into pots with mineral wool and cultivated for two growth periods (GPs). On top of the mineral wool a thin layer of gravel was used to avoid algal growth. The seven mother trees originate from central Sweden, therefore, photo- and thermoperiodic conditions characteristic of that area were used in our experiment (Jonsson et al., 1992) except for winter which was shortened (cf. Table 1).

There were five main replications (blocks) of the experiment. Harvests took place at the week numbers indicated in Table 1. Within each replication, each family was represented by 18 totally randomized seedlings.

At least one hour before applying nutrients, saturation of the substrate with distilled water was carried out. An amount of 2 ml of nutrient solution per plant was applied on every occasion with varying nitrogen amount according to a dose curve calculated in advance (cf. Jonsson et al., 1997). During GP1 the nutri-

Stages	Week No. after sowing		Night length (h)	Temperature, °C	
	GP1	GP2		Day	Night
I Sowing	1-2		6	25	15
II Growth	3-10	28-30*	6	25	15
III Growth retardation	11-18	31*, 32*-38	gradual increase of one hour/week until 14	20	10
IV Resting stage	19-21	39-43*	16	20	10
	22		16	15	5
V Breaking of dormancy	23		16	15	5
	24		16	10	5
	25		16	5	5
	26		24	2	2
	27*		16	10	5

**Table 1.** Cultivation conditions in a growth chamber for two growth periods

\* indicates week numbers when harvests had been carried out

ent solution was applied every second day except for the period of weeks 22-27 after sowing (end of resting stage – breaking of dormancy stage). At that time, owing to limited growth, watering was done only twice a week. Watering and nutrient addition were done in the same way during the early part of GP2 as well. At week 31, 17 days from the beginning of the GP2, the daily nutrient additions were started. Totally, 10 mg of nitrogen were applied to each seedling during GP1 and 42 mg during GP2 (cf. Jonsson et al., 1997). Osram HQIE-250 W/D lamps were used as a light source with an irradiance of about  $320 \text{ mE} \times \text{m}^{-2} \times \text{s}^{-1}$  (400-700 nm) at plant level. During weeks 25-26 after sowing (breaking of dormancy stage) it was reduced to about  $90 \text{ mE} \times \text{m}^{-2} \times \text{s}^{-1}$ . The relative air humidity was 75%.

*Assessments*

The measurements of seedling height to the top of the leader were made monthly during GP1 and weekly during the GP2, except for the period of the most intensive growth when they were performed twice a week.

Five harvests were carried out according to the seedling height growth curve drawn up in an earlier experiment (Jonsson et al. 1997), three during the stage of the most intensive height growth during GP2, and one at the end of each GP. In order to calculate nitrogen productivities at different stages of seedling growth, nitrogen in needles was analyzed after each harvest.

The above-ground plant parts were put in paper bag and dried for 40 hours at 70°C. Afterwards, the needles were separated from the branches and were dried under the same temperature regime for another hour. Then needles as well as stems with branches were weighed in order to determine the dry weights. Dry weight of roots was estimated indirectly by weighing dried pots (64 hours at 70°C) with the substrate before planting and after harvesting the above ground plant part. After grinding the needles, the nitrogen content was determined by an Elemental Analyzer NA 1500, Rodano, Italy.

In order to avoid possible errors caused by outliers, plants with a total dry weight less than 2 standard deviations of the mean value at each harvest were excluded from the calculations. Thirty seedlings out of 640 were eliminated in this way. The traits studied are presented in Table 2.

*Calculations*

The following equation was used to calculate the N productivity:

$$N \text{ prod} = \frac{R_g}{N \text{ conc}} \tag{1}$$

where: N prod is nitrogen productivity ( $\text{g DW} \times \text{mg N}^{-1} \times \text{day}^{-1}$ ),  $R_g$  is relative growth rate between the harvests concerned ( $\text{g} \times \text{g DW}^{-1} \times \text{day}^{-1}$ ), N conc is nitrogen concentration in needles estimated after each harvest ( $\text{mg N} \times \text{g DW}_{\text{needles}}^{-1}$ ).

**Table 2.** Growth chamber traits of the present experiment used for analyses.

Growth chamber traits	Evaluation unit	Annotation
DURGP2	days	Period of the most active height growth (from 10% to 90% of the increment during GP2 only).
DW	g	Plant total dry weight at a certain harvest.
DW <sub>in</sub>	g	Initial plant total dry weight (for estimation cf. Materials and methods).
DW <sub>needle</sub>	g	Needle dry weight at a certain harvest.
Height	mm	Seedling height to the top of the leader assessed monthly during GP1 and weekly or twice a week during GP2.
N conc	mg N·g DW <sub>needle</sub> <sup>-1</sup>	N concentration. (Nitrogen concentration in needles evaluated after each harvest).
N prod	g DW·mg N <sup>-1</sup> ·day <sup>-1</sup>	Nitrogen productivity. (Described in Materials and methods).
N prod <sub>approx</sub>	mg DW·mg N <sup>-1</sup> ·day <sup>-1</sup>	Approximate nitrogen productivity. (Described in Materials and methods).
N utiliz	mg DW·mg N <sup>-1</sup>	Nitrogen utilization. (Described in Materials and methods).

We chose to express the nitrogen productivity on a needle-N basis instead of plant-N basis because of convenience and because of the strong relationship between leaf nitrogen and plant growth demonstrated by Ingestad and McDonald (1989) and Ågren (1983).

Relative growth rate ( $R_g$ ) was calculated by use of equation 2:

$$R_g = \frac{\ln \frac{R_{DW\ n}}{R_{DW\ m}}}{t} \quad (2)$$

where:  $R_{DW\ n}$  is relative total dry weight at harvest “n” (g),  $R_{DW\ m}$  is relative total dry weight at some earlier harvest “m” (g),  $t$  is number of days between harvests “m” and “n”.

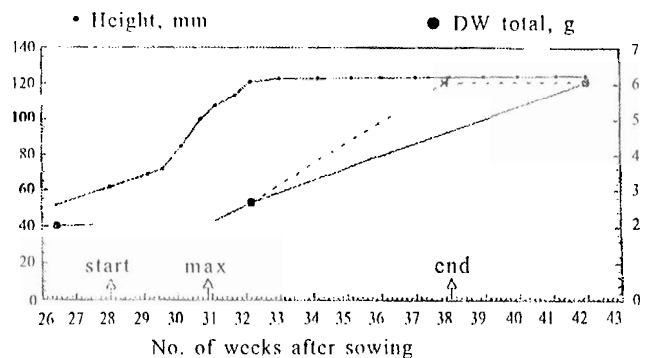
The relative dry weight,  $R_{DW}$ , was calculated by using equation 3:

$$R_{DW\ m} = \frac{DW\ m}{DW\ in} \quad (3)$$

where:  $DW\ m$  is total dry weight at the harvest “m” (g),  $DW\ in$  is initial total dry weight (g).

Initial dry weight was regarded as 20% of the fresh weight at the time of transplanting, i.e. two weeks after sowing (Ingestad and Kähr, 1985). Since different plants were harvested on the different occasions the calculations of N productivity had to rely on family mean values. The original intention was to calculate N productivities for the period of the most active height growth (harvests 2 and 4). However, the dry weight increment

between these two harvests was minute (cf. Figure 1). Therefore, we calculated N productivities based on harvests 2, 4, and 5 as well as two extra N productivities using extrapolated N concentration values (Table 3).



**Figure 1.** Seedling height growth and total dry weight production for the family with the highest N utilization during the second growth period. The arrows indicate start, maximum and end of N addition, the cross marks the point of assumed end of an increase in dry weight.

To estimate the N concentration in the plants at the end of their growth period, we assumed no dry weight increase after the night length reached 12 hours and the nutrient additions were finished (cf. Figures 1 and 2). On this day, 259 from sowing, we extrapolated the N concentration in Figure 2.

In order to compare the present results with data obtained by Jonsson et al (1997), the approximate nitrogen productivity was calculated in the following way:

Table 3. List of nitrogen productivities used for analyses

Character	Period concerned/(No. of days)	Inter family mean (g DW×mg N <sup>-1</sup> ×day <sup>-1</sup> )	Comments
<b>Present experiment</b>			
N prod <sub>approx</sub>	Period of most active height growth(26*)	10.6**	Calculated according to the simplified requirements.
N prod 2-5	harvest 2 - harvest 5(89)	1.2	Extrapolated values of N concentration at the day 259 were used.
N prod 4-5	harvest 4 - harvest 5(71)	1.1	
N prod 2-4	harvest 2 - harvest 4(18)	0.9	
N prod 4-extrap	harvest 4 - day 259(35)	1.7	
N prod 3-extrap	harvest 3 - day 259(45)	1.8	
<b>Previous experiment</b>			
N prod <sub>approx</sub>	Period of most active height growth(34*)	8.9**	Calculated according to the simplified requirements.

\* indicates mean value of the seven families.

\*\* shows the values estimated in mg DW×mg N<sup>-1</sup>×day<sup>-1</sup>

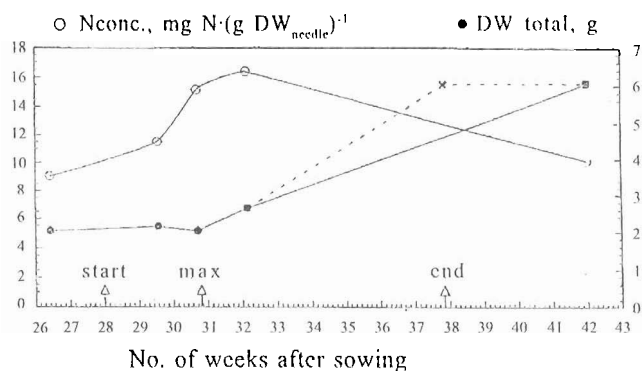


Figure 2. Needle N concentration and total dry weight production for the family with the highest N utilization during the second growth period. The arrows indicate start, maximum and end of N addition, the cross marks the point of assumed end of an increase in dry weight.

$$N \text{ prod}_{\text{approx}} = \frac{0.766 \cdot DW}{DW_{\text{needle}} \cdot N \text{ conc}} \cdot \text{DURGP2} \quad (4)$$

where: 0.766 is the average fractions of biomass produced during GP2 estimated in the previous experiment (cf. Jonsson et al., 1997), DW is total plant dry weight at the end of the experiment (g), DW<sub>needle</sub> is needle dry weight at the end of the experiment (g), N conc is nitrogen concentration in needles at the end of the experiment (mg N×g DW<sub>needle</sub><sup>-1</sup>), DURGP2 is the period of most intensive height growth (cf. Table 2).

Besides N productivity, the nitrogen utilization (dry weight production per unit of nitrogen taken up) was calculated as well. The following equation was used for computing N utilization:

$$N \text{ utiliz} = \frac{DW}{DW_{\text{needle}} \cdot N \text{ conc}} \quad (5)$$

where: DW is total plant dry weight (g), DW<sub>needle</sub> is needle dry weight (g), N conc is nitrogen concentration in needles (mg N×g DW<sub>needle</sub><sup>-1</sup>).

In order to compare present and previous estimates, the N utilization was calculated in this experiment for the last harvest only. Before calculating N productivities and N utilizations, correction of N concentration in the needles for the minimum internal concentration of 4 mg N×g DW<sub>needle</sub><sup>-1</sup>, required for growth's occurrence and corresponding to structural N, was performed (cf. Ingstad and Kähr 1985).

Procedure CORR of the SAS software was used for estimating strength and significance of Pearson's rank correlations between the characters of the present and the previous experiment (SAS, 1988).

Results

A pairwise comparison of the same traits in the two experiments (Tables 4, 5) shows that their values in the previous experiment were consistently higher than in the present experiment with the exceptions of N concentration (Table 4) and approximate N productivity (Table 5). Family ranking for different traits differed both within and between the experiments. Except for the duration of the most active growth (DURGP2), family 18 was fairly consistent with respect to ranking.

As seen from Figure 1 (data from the family with the highest nitrogen utilization), only a limited part of dry weight production during GP2 was produced at the time for height growth completion which was as low as approximately 18.6% as compared to an overall family mean.

The nitrogen concentration (Figure 2) reached the highest levels at harvests 3 and 4 (15.2 and 16.4 mg N×g DW<sub>needle</sub><sup>-1</sup>, respectively). At the end of the present experiment, nitrogen concentration was slightly higher than the N concentration at the end of the previous experiment (cf. Table 4).

From Table 6 it is evident that the approximate N productivity of the previous experiment did not correlate well with any of the N productivities in the present experiment.

Figure 3 illustrates that four of the seven relationships including N utilization as one component, were significant. All the relationships were positive.

Of the correlations among the six different N productivities in the present experiment, only the correlation between N productivities 4-5 and 4-extrap was significant (Table 6). Most of the other correlations did not exceed +0.60. The N concentration was negatively cor-

**Table 4.** N concentration values at five harvests for the present growth chamber experiment and for the end of the previous growth chamber experiment (from Jonsson et al. 1997). Family ranking presented in parentheses.

Family No.	Present experiment						Previous experiment
	mg N/g DW <sub>needle</sub> <sup>-1</sup>						Final harvest
	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5		
1	9.3 (3)	11.9 (4)	15.8 (2)	16.1 (7)	10.7 (2)	9.4 (5)	
7	10.4 (1)	12.0 (3)	15.6 (3)	16.8 (3)	10.3 (5)	9.2 (6)	
8	9.8 (2)	12.6 (1)	16.6 (1)	16.9 (2)	10.7 (3)	10.3 (1)	
9	9.2 (5)	12.5 (2)	15.5 (4)	16.6 (4)	10.3 (6)	9.7 (3)	
10	8.7 (7)	11.1 (7)	14.9 (6)	16.2 (6)	11.0 (1)	9.9 (2)	
17	9.3 (4)	11.4 (6)	14.6 (7)	16.9 (1)	10.5 (4)	9.2 (7)	
18	9.1 (6)	11.5 (5)	15.2 (5)	16.4 (5)	10.2 (7)	9.3 (4)	
Mean	9.4	11.9	15.5	16.6	10.5	9.6	

**Table 5.** Values of various traits of the present and the previous experiment. Family ranking presented in parentheses. Units are presented in Table 2.

Family No.	N productivity			N utilization		DW		Height		DURGP2	
	Present experiment		Previous experiment	Present experiment	Previous experiment	Present experiment	Previous experiment	Present experiment	Previous experiment	Present experiment	Previous experiment
	N prod 4-extrap	N prod <sub>approx</sub>	N prod <sub>approx</sub>								
1	1.7 (4)	9.9 (6)	10.1 (1)	329 (2)	405 (3)	5.9 (3)	6.8 (3)	140 (1)	153 (2)	29.2 (2)	32.1 (7)
7	1.6 (6)	11.7 (2)	8.7 (4)	307 (5)	373 (4)	4.9 (7)	6.5 (5)	114 (6)	149 (3)	22.5 (6)	34.2 (5)
8	1.6 (7)	10.2 (4)	7.7 (7)	307 (6)	328 (7)	5.3 (6)	6.1 (7)	135 (2)	144 (4)	24.6 (5)	34.4 (4)
9	1.9 (2)	10.3 (3)	8.2 (6)	326 (3)	367 (5)	6.0 (2)	6.6 (4)	123 (4)	136 (6)	29.6 (1)	35.5 (1)
10	1.7 (5)	8.5 (7)	8.5 (5)	295 (7)	356 (6)	5.5 (5)	6.2 (6)	115 (5)	131 (7)	28.2 (3)	33.9 (6)
17	1.9 (1)	10.1 (5)	9.4 (3)	317 (4)	408 (2)	5.7 (4)	7.2 (2)	114 (7)	136 (5)	27.4 (4)	35.3 (2)
18	1.8 (3)	13.4 (1)	9.6 (2)	336 (1)	414 (1)	6.1 (1)	7.5 (1)	125 (3)	158 (1)	21.5 (7)	34.7 (3)
Mean	1.7	10.6	8.9	316.7	378.7	5.6	6.7	123.7	143.9	26.1	34.3

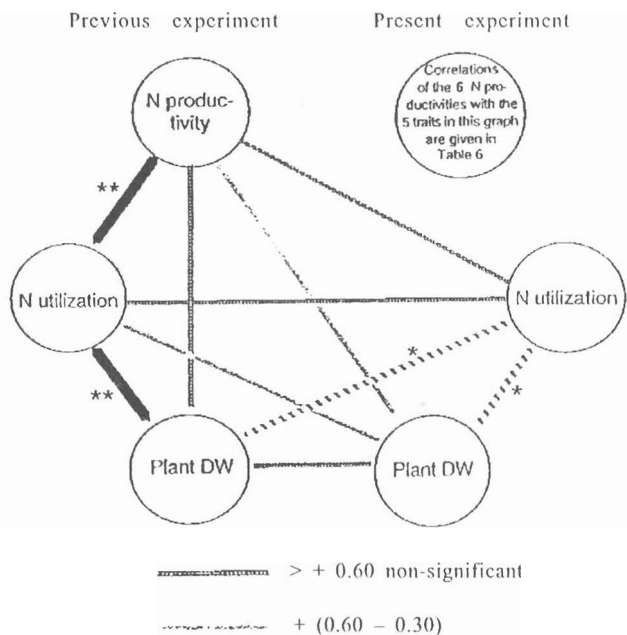
**Table 6.** Pearson's rank correlation coefficients and their significances (\* - significant at 5% level, \*\*\* - at 0.1% level, respectively) for relationships between N productivities, N utilizations and DWs from the two growth chamber experiments and N concentration and height for the present experiment. Note that there may be autocorrelations within an experiment between plant dry weight on one hand and N productivity and N utilization on the other hand.

Variables	Present experiment									Previous experiment		
	N prod <sub>approx</sub>	N prod 4-5	N prod 2-5	N prod 2-4	N prod 4-extrap	N prod 3-extrap	N conc	Height	N prod <sub>approx</sub>	N util	DW	
1	2	3	4	5	6	7	8	9	10	11	12	
<b>Present experiment</b>												
N prod <sub>approx</sub>							-0.70	-0.06	0.28	0.37	0.58	
N prod 4-5	0.28						-0.60	-0.35	0.28	0.58	0.68	
N prod 2-5	0.37	0.56					-0.74	0.06	-0.30	-0.06	0.10	
N prod 2-4	0.18	-0.14	0.75				-0.37	0.39	-0.57	-0.54	-0.43	
N prod 4-extrap	0.08	0.97***	0.38	-0.32			-0.39	-0.37	0.34	0.60	0.64	
N prod 3-extrap	0.17	-0.21	0.41	0.69	-0.30		-0.22	0.84*	-0.05	-0.16	-0.12	
N utilization	0.60	0.58	0.46	0.10	0.50	0.50	-0.69	0.42	0.59	0.70	0.78*	
DW	0.14	0.56	0.18	-0.21	0.62	0.36	-0.25	0.32	0.50	0.58	0.63	

related with N productivities (Table 6), N utilization, and plant dry weight (Figure 4). Noteworthy is that both dry weight and N utilization correlated poorly with final plant height.

**Discussion and conclusions**

We limited this study to seven families selected in a representative way to evaluate if the approximate meth-



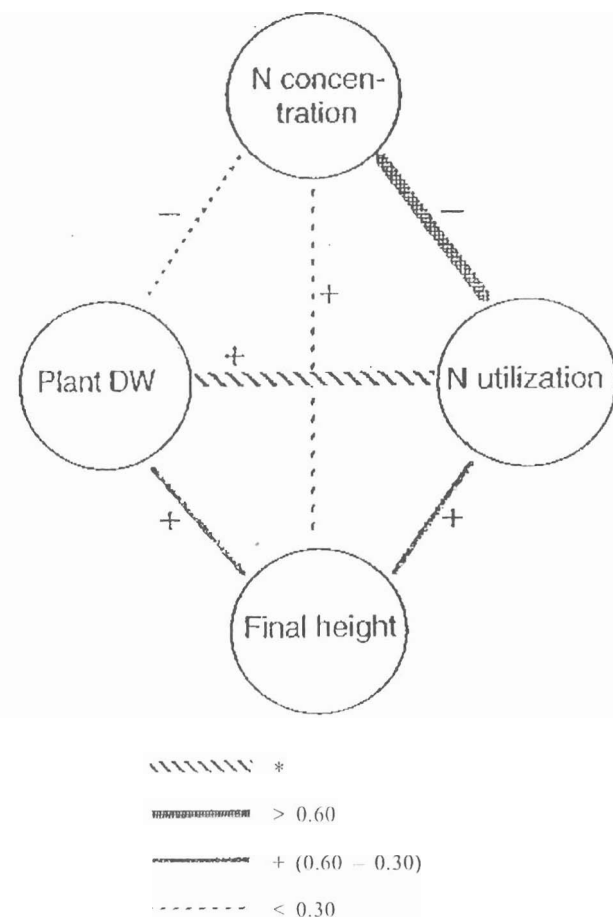
**Figure 3.** The relationships among various characters studied in the present and previous experiments

od for determination of N productivity used by Jonsson et al. (1997) gives a good estimate of the N productivity as defined by Ingestad (1979). For cost and space reasons seven families constitute an upper limit that could be dealt with. Seven families is also a minimum for estimates of family mean correlations between two traits. However, a selection that is representative as regards N productivity does not necessarily give a selection representative as regards other traits. Therefore, not only significance of correlations, but also trends in relationships among all the traits will be discussed.

It should be noted that, within an experiment, there may be autocorrelations between N utilization and plant dry weight since the latter is numerator in the derivation of N utilization. Similarly, part of the dry weight is the numerator in the derivation of the N productivities.

*N productivity*

The main objective of this investigation was to study if the approximate N productivity per day according to Jonsson et al. (1997) was a good estimate of a physiologically more appropriately estimated N productivity. As is evident from column 10 of Table 6 there was a poor agreement between the approximate N productivity of the previous experiment and all the N pro-



**Figure 4.** The relationships among N concentration, N utilization, plant height, and total dry weight at the end of the present experiment. + and - indicate positive and negative correlation coefficients

ductivities of this experiment. Moreover, the two N productivities estimated in the same way in the two experiments had a correlation coefficient as low as 0.28. The most probable reason for this weak relationship is the poor agreement between the family DURGP2s in the two experiments, the latter relationship having an estimated family mean correlation coefficient of -0.10 (not shown). This must partly be attributed to the low variation of this trait – the largest difference between the family means was 3.4 days in the previous experiment as compared to 8.1 days in the present experiment. Since DURGP2 is the denominator in the formula for derivation of approximate N productivity this difference between the two experiments has a great impact on the estimate of this trait. The reduced growth in the present experiment might also have contributed to the discrepancy between two N productivities estimated in the same way in the two experiments.

The difference in DURGP2 of the two experiments was unexpected since growth rhythm traits are shown to keep the family ranking from growth season to growth season (Mikola 1980). It is also unexpected in view of our finding of fairly strong and non-significant relationships between plant dry weights ( $r = 0.63$ ) and N utilizations ( $r = 0.70$ ) of the two experiments (see also Figure 3).

Since the planned harvests were based on height growth and height growth did not reflect the dry weight growth (cf. Figure 1) there was a problem of estimating N productivity during the exponential phase of dry weight growth under steady state nutrient conditions as done by e.g. Ingestad (1979). Therefore, we made several estimates of the N productivity in our investigation. With three exceptions the correlation coefficients among all N productivities of the present experiment were weak, not exceeding 0.60 (Table 6 columns 2-6). It is worth mentioning that the extrapolated N productivity "N prod 4-extrap" (cf. Table 3), that might come closest to the requirement of including the exponential phase of dry weight growth, had the strongest, however, non-significant, relationship with plant dry weight ( $r = 0.62$ ). It also had the strongest relationship with the approximate N productivity of the previous experiment, although still weak ( $r = 0.34$ ).

In spite of the possibility of autocorrelation between N productivities and plant dry weight, the correlations between these two traits in each of the experiments were never really strong.

#### *Other traits*

Since the seven families were selected in order to cover the range of approximate N productivity in the previous experiment this means that the seven families did not cover the full range as regards the other traits. In spite of this we noted strong and significant correlations between N utilization in the present experiment and the plant dry weights in both experiments (Figure 3). The correlation of N utilization of the previous experiment with plant dry weight in the present experiment was estimated at 0.58. The N utilizations of the two experiments were strongly correlated with each other (0.70). These data suggest that N utilization can be assessed with repeatability and that it is a fairly good predictor of dry weight production even in other experiments. Moreover, it was shown to be one of the best juvenile traits to predict field performance (Abraitis et al. 1998).

The weak relationship between final height and other traits in the present experiment is striking (Figure 4, Table 6). Thus plant height does not reflect the plant dry weight. We are not aware of any genetic studies in which the growth rhythms of height growth and dry weight production were studied simultaneously. Therefore, we do not know if our results are unique or general. It is desirable for studies of nutrient productivities to have knowledge about the growth rhythm of dry weight production. However, for genetic studies such experiments would be hard to carry out for space and cost reasons.

The plant N status did not remain constant during the growing season in this investigation. The needle nitrogen concentration peaked at harvests 3 and 4 (mean values 15.5 and 16.6 mg N × g DW<sub>needle</sub><sup>-1</sup>, respectively), i.e. during the period of most active height growth and largest nutrient additions. Since the peak in nutrient addition preceded the peak in biomass production it is possible that part of the nitrogen was taken up in excess of growth requirements, thus lowering the N productivity at this stage of plant development.

As expected, the N concentration was strongly negatively correlated with N utilization (Figure 4). The more biomass produced per nitrogen unit in the plant, the larger the N utilization will be. It is somewhat surprising that the negative relationship between N concentration and plant dry weight was not stronger (Figure 4).

In conclusion, an answer to the question whether the approximate N productivity is a good estimate of true N productivity in the sense of Ingestad (1979) cannot be definitely given based on the data from this investigation. It remains to cultivate the families in so called Ingestad boxes and estimate the N productivity from such an experiment. However, N utilization could be estimated with a satisfactory repeatability and was fairly strongly correlated with dry weight and thus may be utilized in future experiments.

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## References

- Abraitis, R., L. Norell and G. Eriksson. 1998. Retrospective Studies on Nitrogen Response of *Pinus sylvestris* L. Forest Genetics 5(1): 47-53.
- Ågren, G. I. 1983. Nitrogen productivity of some conifers. Can. J. For. Res. 13: 494-500.
- Hägglund, B. and L.G. Svensson. 1982. Svensk skogsmark – bördighet och ståndortsförhållanden. In: Skogsfakta, Inventering och ekonomi 2: 4 p.
- Ingestad, T. 1979. Nitrogen Stress in Birch Seedlings II. N, P, K, Ca, and Mg Nutrition. Physiol. Plant. 45: 149-157.
- Ingestad, T. and M. Kähr. 1985. Nutrition and growth of coniferous seedlings at varied relative nitrogen addition rate. Physiol. Plant. 72: 450-459.
- Ingestad, T. and A. J. S. McDonald. 1989. Interaction between nitrogen and photon flux density in birch seedlings at steady-state nutrition. Physiol. Plant. 77: 1-11.
- Jahromi, S. T., R. E. Goddard and W. H. Smith. 1976. Genotype x Fertilizer Interactions in Slash Pine, Growth and Nutrient Relations. For. Sci. 22: 211-219.
- Jonsson, A., I. Dormling, G. Eriksson and L. Norell. 1992. GCA Variance Components in 36 *Pinus sylvestris* L. Full-Sib Families Cultivated at Five Nutrient Levels in a Growth Chamber. For. Sci. 38: 575-593.
- Jonsson, A., T. Ericsson, G. Eriksson, M. Kähr, K. Lundkvist and L. Norell. 1997. Interfamily Variation in Nitrogen Productivity of *Pinus sylvestris* seedlings. Scand. J. For. Res. 12: 1-10.
- Mikola, J. 1980. The effect of seed size and duration of growth on the height of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) provenances and progenies at the nursery stage. Silva Fenn. 14: 84-94.
- Millard, P. 1996. Ecophysiology of the Internal Cycling of Nitrogen for Tree Growth. Z. Pflanzenerähr. Bodenk. 159: 1-10.
- Pritchett, W. L. and R. E. Goddard. 1967. Differential Responses of Slash Pine Progeny Lines to Some Cultural Practices. Soil Sci. Amer. Proc. 31: 280-284.
- Rohrerds, J. H., G. Namkoong and C. D. Davey. 1976. Family Variation on Growth Response of Loblolly Pine to Fertilizing With Urea. For. Sci. 22: 291-299.
- SAS Institute Inc. 1988. SAS Procedures Guide, Release 6.03 Edition. Cary, NC: SAS Institute Inc. 441 p.
- Sheppard, L.J. and M. G. R. Cannell. 1985. Nutrient Use Efficiency of Clones of *Picea sitchensis* and *Pinus contorta*. Silvae Genet. 34: 126-132.
- Tamm, C.O. 1991. Nitrogen in terrestrial ecosystems. Questions of productivity, vegetational changes, and ecosystem stability. In: Ecological Studies. Springer-Verlag, Berlin, Heidelberg, New York, London, Paris, Tokyo, Hong Kong, Barcelona. 81: 115 p.
- Walker, H.D. and R.D. Hatcher. 1965. Variation in the Ability of Slash Pine Progeny Groups to Absorb Nutrients. Soil Sci. Amer. Proc. 29: 616-621.
- Waxler, M.S. and J.P. van Buijtenen. 1981. Early Genetic Evaluation of Loblolly Pine. Can. J. For. Res. 11: 351-355.

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## УСВОЕНИЕ АЗОТА САЖЕНЦАМИ СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS* L.) СЕМИ СЕМЕЙ СВОБОДНОГО ОПЫЛЕНИЯ

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### Резюме

Приблизительный метод эффективности освоения азота (увеличения биомассы и азота за определенное время) у саженцев сосны обыкновенной (*Pinus sylvestris* L.), который применялся в предыдущем опыте, был сравнен с более старым методом, требующим большего числа саженцев и исследований деструктивной вырубкой. Для опыта отобраны саженцы 7 семей свободного опыления, которые имели наиболее контрастное освоение азота (N), выявленное по приближительному методу, при выращивании саженцев в климатических камерах в течение двух вегетативных периодов, составляющих 43 недели. В течение первого вегетационного сезона высота саженцев измерялась ежемесячно, а во втором сезоне – еженедельно или дважды в неделю. Учет освоения N во втором сезоне роста проводился пятикратно путем физиологического метода. Сухая масса различных частей саженцев и концентрация N в хвое устанавливалась после каждого учета.

На этой основе определено освоение и потребление N. Была установлена слабая корреляционная связь между увеличением высоты саженцев и их биомассы. Сопоставление одних и тех же признаков в обоих опытах показало, что, за исключением нескольких случаев, показатели, полученные в предыдущем опыте, были выше. Приблизительное освоение N в первом опыте имело слабую корреляцию со вторым, показывая, что приближительный подсчет освоения N является недостаточным, чтобы заменить физиологический подсчет. Несмотря на это, была установлена достаточно высокая корреляция между потреблением азота в обоих опытах, что дает повод полагать, что определение освоения N, как достоверного свойства, возможно в дальнейших исследованиях.

**Ключевые слова:** сосна обыкновенная, климатическая камера, освоение азота, потребление азота, семьи свободного опыления, сухая масса.