The Effect of Fertilization on Norway Spruce (*Picea abies* (L.)) Graft Foliage in the Pauska Seed Orchard, Estonia

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Altogether, 1,003 grafts were studied in the Pauska Seed Orchard, South Estonia, in 1988-1993. The progenies of 4 clones as well as 5 different kinds of fertilizers (N, P, K, NPK and the control group) were used in the research. The effects of three factors (fertilization, the clone and the year) on different characteristics of spruce grafts were studied. The general linear method (the GLM procedure) of the SAS software package was used to determine the dependence of the characteristic features. In addition, the morphological features and the nutrient content of needles were explored.

The research showed that the most important factor influencing spruce grafts was the year. It had a significant effect on nearly all the characteristics dealt with in this work. It also appeared that the clone influenced all needle attributes as well as their nutrient content. Different fertilizers influenced the nutrient content of graft needles as well as needle size and weight. Ammonium nitrate increased needle length and weight as well as N content yet decreased needle Mg, Ca and, to some extent, K content. Superphosphate increased needle length and weight as well as P content but decreased their Mg content. Potassium fertilizers increased needle K content yet decreased their P and, to some extent, Mg content. Complete fertilization led to an increase in needle length and weight as well as N and P content on the one hand and a decrease in needle Mg content on the other.

Key words: Norway spruce, seed orchard, fertilization, needles, clone, year factor

Introduction

When seed orchards were first proposed there was considerable enthusiasm among silviculturists, for two reasons. The first was obvious – seed orchards had the promise of making available seed of better genetic quality. The second was associated with the hope that seed orchards would boost seed availability, production, accessibility and ease of collection (Giertych 1987).

The improvement of graft nutrial conditions using mineral fertilizers plays a significant role in a system of methods stimulating seed bearing. As grafts require much energy for creating generative organs and producing cones, they need plenty of nutrients. According to R. Sarvas (1970), fertilization is one of the most efficient means in boosting graft development. Fertilization is also required when the proportions of different nutrients to each other differ from what is considered optimal. For normal nutrition, the optimal ratio of nutrients (N:P:K) in spruce needles should be 7:1:3 (Valk, Raid 1994).

The nutrient most commonly used in fertilization trials is nitrogen. Fertilization with nitrogen leads to extra weight gains in spruce roots, branches and stem; at the same time, however, it reduces the phosphorus and potassium content of tissues by 15–20% (Суворов 1974). According to the previous analyses (Salih, Andersson 1999), N alone and N combined with P have a growth-retarding effect. At the seed orchard, graft growth is not the only objective; rather, our research is focused on seed-bearing capacity. It has been reported, however, that repeated applications of N alone have no effect on the P, K and Mg levels in current-year needles (Jacobson, Pettersson 2001). In Sweden, it has been observed that orchard tree needles on average contain more nitrogen and phosphorus, compared to forest tree needles (Rosvall, Ununen 1982) while the potassium levels are similar. Despite the high N content, nitrogen fertilization is the primary recommendation, since denser crowns contribute to the formation of strobiles. However, fertilization programs also include phosphorus and potassium as supporting and nutrition-balancing elements, as well as microelements. Studies on the fertilization of spruce seed orchards have not been as numerous as those of pine seed orchards. No research had previously been performed in Estonian spruce seed orchards. Analyses have been conducted on the effect of fertilization on spruce seedlings (Raid 1985, 1992, 1996), forest plantations (Raid 1992, Valk, Raid 1994) and spruce stand seed-bearing capacity (Валк 1974, Talli 1977).

The objective of this paper is to clarify the effect of fertilization on different spruce graft attributes, particularly on foliage formation. As well, the authors endeavor to establish the effect of the clone as well as that of the weather conditions of the year on needle attributes in spruce seed orchards.

Material

At a seed orchard, the crowns and the nutritive uptake areas of grafts are larger than those of trees in a stand. Therefore, the establishment of a trial requires a larger area with a uniform structure in terms of both the relief and the soil. The number of grafts per area unit is small, which attaches importance to the attributes of each individual graft.

The fertilization trials were established in the spring of 1988 at Pauska I Seed Orchard founded on a former farming field (sod-podzolic soil). The orchard is situated at Kõpu, Viljandi County (58°20'N and 25°21'E, Figure 1). Its total area is 13.63 ha. The seed orchard accommodates 98 clones and 2,898 grafts,

Figure 1. The Pauska seed orchard in Estonia

which makes 213 grafts per hectare. For the trial, clones having a greater number of grafts were selected on compartments situated close to each other. The trial objects were grafts of Clone K1 of a low seed-bearing capacity and of Clone R3 of a high seed-bearing capacity planted in 1970 on Compartment 12 (at the planting density of 5x5 m) and progenies of Clones VL37 and VL67 planted in 1978 on Compartment 1 (10x10m).

The grafts were investigated for six years (1988–1993) following fertilization. The effective temperature sum (degree days, d.d., threshold value +5 °C) of the period totaled from 1300° d.d. (in 1993) to 1700° d.d. (in 1998). Over the trial period in the Pauska spruce seed orchard, the cumulative total precipitation was lowest in 1992, when it constituted only 325 mm, and highest in 1988, when it amounted to 550 mm (Agrometeoroloogiline ülevaade ["Agrometeorological Review"], 1990, 1991, 1994, 1995).

The fertilizers used were ammonium nitrate, superphosphate and potassium chloride. Fertilizer amounts are given in kilograms of agent per hectare. Fertilizers were applied manually on a graft-by-graft basis and circularly around a tree, making sure that the trees under study would not be situated next to each other and that each trial variant would involve progenies of the same clones. The scheme of five trial variants of N300; P300; K300; N200P300K150 and the control variant, which was deemed to be more informative about the efficiency of different nutrient elements, was used in the trial.

Needles were gathered graft by graft from the last-year whorl in the first ten-day period of November during six years. One shoot was collected from the last-year's branch whorls of each graft on the Pauska spruce seed orchard trial area for conducting needle analyses. Needle density per 1 dm, the length of 50 needles and the dry weight of 100 needles were determined. Immediately after needle measurements and the determination of needle density the needles were dried.

The chemical analyses of needles (N, P, K, Ca and Mg content) performed at the Soil Laboratory of the former Estonian Forest Institute shed light on graft nutritional conditions. For total nitrogen analyses, the Kjeldahl method was used (digestion with concentrated H_2SO_4, distillation with NaOH and titration with a 2% H_3BO_3 solution). For P, K, Ca and Mg analyses, incineration at the temperature of 400°-500°C with a 25% HCl solution was used. The phosphories content was determined colorimetrically, the potassium content by a flamephotometer, and the calcium and magnesium contents by titration.

Methods

To process the data gathered, Version 8.0 of the applied statistics software package SAS was used (SAS Institute Inc., 1997). The list of the variables analysed and their summary statistics (sample count, arithmetical mean, standard deviation, the minimum, the maximum and the quartiles) are given in Table 1.

Table 1. Summary statistics of the variables of spruce grafts: number of observations (N); arithmetical mean (m); standard deviation (s); minimum and maximum; lower quartile ($x_{0.25}$) and upper quartile ($x_{0.75}$)

Variables	N	m	s	Min	Max	$x_{0.25}$	$x_{0.75}$
Needle length, mm	943	11,78	2,48	7,30	20,90	9,80	13,60
Weight of 100 needles, g	936	0,57	0,18	0,20	1,44	0,42	0,70
Density of needles, dm^{-1}	943	123,53	63,22	12,5	400,00	76,90	166,70
Content of N in needles, %	831	1,34	0,29	0,69	2,29	1,14	1,50
Content of P in needles, %	837	0,25	0,06	0,13	0,90	0,20	0,28
Content of K in needles, %	837	0,73	0,26	0,25	1,81	0,55	0,89
Content of Mg in needles, %	837	0,18	0,08	0,04	0,54	0,12	0,22
Content of Ca in needles, %	837	0,51	0,14	0,19	1,02	0,42	0,60
The content of N for N:P:K	831	58,30	7,76	31,35	85,47	54,61	63,41
The content of P for N:P:K	831	10,62	1,84	3,42	17,07	9,41	11,91
The content of K for N:P:K	831	31,08	7,51	11,11	57,03	26,37	34,21

To investigate relationships between variables, use was made of the SAS generalized linear methods procedure GLM, which incorporates the possibilities of both variance analysis and regression analysis. The effects of the three factors studied (fertilization, the clone and the year) on different variables have been summed up in Table 2. The distribution characteristics of variables are presented on boxplots. Boxplots and scatter plots have been drawn up using the freeware statistics package R (via http://cran.r-project.org). In addition to the main effects of the three above-mentioned factors, their crossed effects as well as the correlations between continuous variables were investigated. Some of the most remarkable of these have been presented in the textual part of the analysis.

The Tukey studentized range test on all main effect means was performed, which identified the levels or level groups differing from each other. The most remarkable patterns have been provided in the text of the analysis.

To clarify the effect of different fertilization variants, the ESTIMATE - statement was used for testing fertilization variant differences compared to the control variant. The differences in and the significances of the means of the fertilized groups and the control group have been presented in Table 3.

Results and discussion

The quantitative indicators of spruce needles indirectly characterize graft nutrial conditions and thus constitute the primary diagnostic attributes.

An important attribute is needle length, since needles respond well to change in nutrient environment (Figure 2). The mean needle length was 11.8 mm. The clone and the year proved to be the most significant factors influencing needle length (significances of factors $p<0.0001$) (Table 2); also reliable was the effect of fertilization ($p<0.03$). These three factors ac-

Table 2. Dependence of graft variables on the factor (year, clone, fertilization). The number of observation (N); the coefficient of determination (r^2); the residual standard error (s); significances of factors (p-values) have been shown in the table. The effect of the factor is considered significant if $p<0.05$

Variables	N	r^2	s	*Factors*		
				Clone	*Treatment*	*Year*
Needle length, mm	943	0,46	1,83	**<0,0001**	**0,0298**	**<0,0001**
Weight of 100 needles, g	936	0,45	0,13	**<0,0001**	**0,0008**	**<0,0001**
Density of needles, dm^{-1}	943	0,56	42,23	**<0,0001**	0,68	**<0,0001**
The connection between the length of the sprout with 100 needles and its increment	137	0,57	3,01	**<0,0001**	070	**0,0020**
Content of N in needles, %	831	0,52	0,21	**<0,0001**	**<0,0001**	**<0,0001**
Content of P in needles, %	831	0,57	0,04	**<0,0001**	**<0,0001**	**<0,0001**
Content of K in needles, %	831	0,75	0,13	**<0,0001**	**<0,0001**	**<0,0001**
Content of Mg in needles, %	831	0,27	0,07	**<0,0001**	**<0,0001**	**<0,0001**
Content of Ca in needles, %	831	0,28	0,12	**<0,0001**	**<0,0001**	**<0,0001**
The content of N for N:P:K	831	0,63	4,78	**<0,0001**	**<0,0001**	**<0,0001**
The content of P for N:P:K	831	0,25	1,61	0.2341	**<0,0001**	**<0,0001**
The content of K for N:P:K	831	0,67	4,32	**<0,0001**	**<0,0001**	**<0,0001**

Table 3. The dependence of fertilization on spruce grafts (the difference between fertilized grafts and the control group)

Variables	N	P	K	NPK
Needle length, mm	**0,531***	**0,368***	0,196	**0,400***
Weight of 100 needles, g	**0,048*****	**0,039****	0,003	**0,027***
Density of needles, dm⁻¹	–5,816	–3,983	–0,847	–2,197
Content of N in needles, %	**0,154*****	0,007	–0,019	**0,140*****
Content of P in needles, %	0,002	**0,021*****	**–0,023*****	**0,010***
Content of K in needles, %	**–0,038***	–0,006	**0,060*****	0,002
Content of Mg in needles, %	**–0,063*****	**–0,029*****	–0,013	**–0,036*****
Content of Ca in needles, %	**–0,070*****	–0,018	–0,017	–0,012
The content of N for N:P:K	**2,342*****	**–1,070***	–0,615	**1,0158***
The content of P for N:P:K	–0,3352	**0,785*****	**–0,855*****	–0,073
The content of K for N:P:K	**–2,006*****	0,285	**1,470****	**–0,943***

* – p=0,05
** – p=0,01
*** – p=0,001

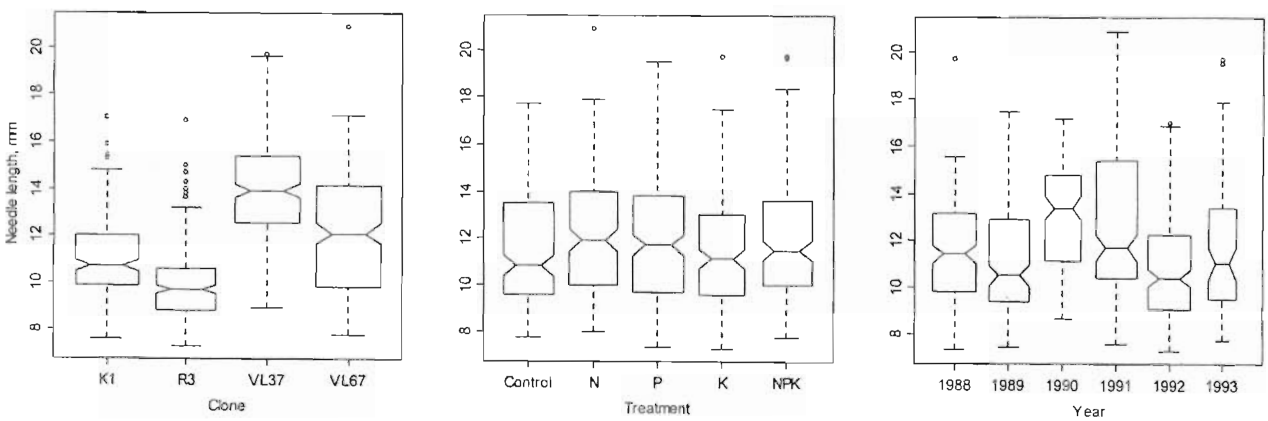

Figure 2. Boxplots of needle length from different clones, treatments and measurement years

counted for a total of 46% of needle length variance. The progenies of each clone had substantial differences in mean needle length, the longest needles being in Clone VL37 (13.89 mm) and the shortest in Clone R3 (9.93 mm). These findings agree with the work done by I. Etverk (1974[1]), according to which both needle length and weight are determined relatively well by heredity. With regard to fertilization variants, clearly distinguished from the others was the needle-length-enhancing effect of nitrogen fertilization, which was the most obvious in Variant N300 ($p=0.005$). Gains in graft needle length were observed following the use of complete ($p=0.032$) and phosphorus ($p=0.043$) fertilizers (Table 3). By year, the needles were longest (13.07 mm) in 1990. The crossed effect of the year and fertilization was insignificant. The year and the clone as well as the clone and the fertilization variant were observed to produce a certain degree of crossed effect; however, inclusion of these factors into the model resulted in just a negligible reduction in the residual standard deviation.

The amount of organic matter produced by foliage is determined by the area of photosynthesis, which can be expressed through needle weight (Figure 3). In our research, the mean 100-needle dry weight was 0.57 g. Needle weight depends on the site and its productivity on the one hand and the combination and the amounts of the mineral fertilizers used on the other (Raid 1985). Like needle length, the 100-needle weight was significantly influenced by the clone and the year ($p<0.0001$); also reliable was the effect of fertilization ($p=0.0008$). The above-mentioned factors accounted for 45% of the needle weight variance. All the clone grafts under study exhibited considerable differences

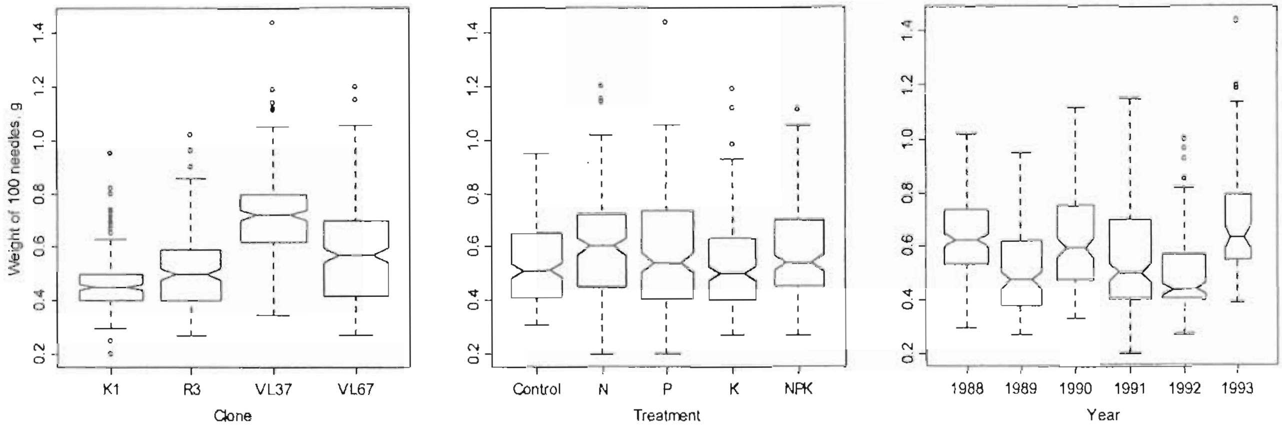

Figure 3. Boxplots of weight of 100 needles from different clones, treatments and measurement years

in the mean needle weight, which ranged from 0.46 grams (Clone K1) to 0.73 grams (Clone VL37). The Tukey test distinguished from the other variants the reliable effect on needle weight of ammonium nitrate (p=0.0004) and superphosphate (p=0.003) fertilization. In a similar manner, I. Etverk's (1969[2]) findings established the equal effect of heredity and fertilization on the morphological attributes of spruce foliage.

The mean needle density in our research was 123 needles per 1 dm of shoots. According to I. Etverk (1969[1]), spruce plantation fertilization results in lower needle density as well as longer and heavier needles. The same developments have been observed in pine grafts (Kurm 1992, 1994). It has been reported that needle density has a moderately strong negative correlation with needle K content (Kurm 1996). In our research, the factors having a considerable effect (p<0.0001) on the foliage appeared to be the clone and the year, which accounted for a total of 56% of the variance. The highest needle density occurred in Clone R3 grafts (198 needles/dm) and lowest in Clone VL37 grafts (79 needles/dm). By year, the highest needle density was observed in 1992 (169 needles/dm) and lowest in 1990 (93 needles/dm). By comparing factor effects on needle density and needle length, it appeared that these are inversely correlated: for instance, the grafts of Clone R3 had the highest density and lowest needle length, as opposed to those of Clone VL37, which had lowest needle density and the greatest needle length. A similar pattern was observed in different years. Providing that a current-year shoot has a constant number of needles and that both needles and shoots make proportional gains in length under favourable growth conditions, it is natural that needle density is negatively correlated with needle length. That finding was confirmed by the general linear method analysis, which showed that the correlation of needle length with needle density was stronger than those of needle density with the clone and the year.

We also investigated the relationship between graft height increment and the length of the parts of shoots containing 100 needles. For that purpose, we had data from 1989 at our disposal. The most influential factor in determining the length of the parts of shoots containing 100 needles was the clone (p<0.0001); also reliable was the effect of height increment (p=0.0020). The longest average 100-needle part of shoot (13.8 cm) was found in the grafts of Clone VL37 and shortest (5.0 cm) in those of Clone R5. There have been reports that fertilization of young spruces with different doses of ammonium nitrate has no effect on shoot length increment and needle weight (Kölling, *et al.* 1997). Excessive applications of NH_4NO_3 led to the depletion of Mg in the substrate. Fertilization increased the mineralization rate of soil organic matter.

Needle nutrient content adequately reflects graft nutrient supply levels. Nitrogen, as one building block of amino acids and thus a necessary component of proteins, is vital for plants. Deficiency in nitrogen reduces photosynthesis intensity to a greater extent than that in any other element. Of all mineral matter deficiencies, it is exactly that of nitrogen that forest trees suffer most from (Pihelgas 1983). According to the foliage standard drawn up by German researchers (Fiedler, *et al.* 1973), spruce needles should have the N content of 1.51-2.0% for optimal growth. Based on our trial data, the mean needle N content was 1.34%. We used the needle nitrogen content model in which needle weight and needle density are regarded as continuous factors whereas the clone, the fertilization variant and the year are considered discrete factors. Needle N content depended substantially (p<0.0001) on discrete factors; also significant were the effects of needle weight (p=0.0002) and needle density (P=0.0023). The strongest effect proved to be that of the year (Figure 4). According to the Tukey test, four groups of needle N content could be identified with regard to the year: 1) 1988 – 1.54%; 2) 1989–1991 – 1.34–1.41%; 3) 1992 – 1.22%; 4) 1993 – 0.95%.

By year, the highest needle P content (0.29%) was observed in the third year of the trial (Figure 5).

Potassium is deemed to play the most significant role in carbohydrate metabolism, for it promotes the photosynthesis of carbohydrates and influences their movement in plants. Potassium stimulates ferments, stabilizes metabolism and regulates plant water regime

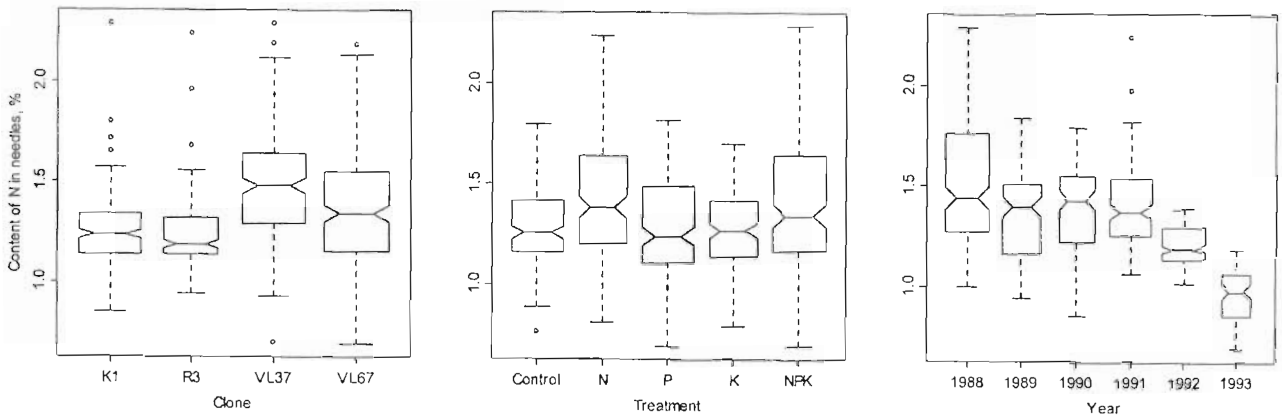

Figure 4. Boxplots of content of N in needles from different clones, treatments and measurement years

With regard to fertilization variants, grafts fertilized with ammonium nitrate and complete fertilizer stood out from the others with their needle N content of 1.43%. Spruce needle nitrogen content was highest in the fall of the first trial year. In the subsequent years, the needle N content experienced a steady decline in all trial variants.

Phosphorus, the amount of which in plants is approximately 10 times smaller than that of nitrogen (Pihelgas 1983), is one component of the most important protoplasmic compounds – nucleic acids. Phosphorus assimilation patterns are not as obvious as those of nitrogen (Raid 1990). According to I. Etverk (1969), the phosphorus content of 10-year-old spruce needles had a moderately positive correlation with needle weight and needle density. Based on our trial data, the mean needle P content was 0.245%. It largely depended on the clone; also significant were the effects of the trial variant and the year as well as the cumulative effect of the two ($p<0.0001$). Clone progenies were distinguishable by their clearly established needle P content. According to the Tukey test, the grafts of Clone VL67 had the greatest P content (0.28%) while those of Clone R3 had the smallest (0.21%). Of fertilizers, needle P content was substantially increased by superphosphate (to 0.26%) and complete fertilizer (to 0.25%), whereas fertilization with potassium chloride resulted in a reduced phosphorus level of 0.21%.

(Mohr, Scopfer 1995). Further, potassium is associated with the metabolism of proteins and amino acids (Pihelgas 1983). A high potassium content of young developing plant parts bears witness to its great importance in growth processes. In our research, the mean needle K content was 0.73%. As reported by German researchers, the K content of spruce needles is 0.64–1.05% under optimal circumstances. According to V.S. Pobedov and other Byelorussian researchers, (Справочник... 1977), the foliage standard dictates a K content of 0.6–0.7%. Based on our data, the different factors accounted for as much as up to 82% of the needle K content variance. The effect of the clone was greatest; all the other factors also had a significant effect on needle K content ($p<0.0001$). Thus, the highest needle K content was observed in the grafts of Clone VL67 (1.01%) and lowest in those of Clone R3 (0.54%). Fertilization with potassium chloride increased needle K content by 0.063%, with superphosphate by 0.029% and with complete fertilizer by 0.036%. By year, needle K content exhibited fairly extensive fluctuations (Figure 6). However, fertilizers containing Cl ions are generally not used anymore for forest fertilization due to a relatively high Cl sensitivity of forest trees (Hüttl 1986).

Magnesium stimulates enzyme formation and influences photosynthesis. Magnesium deficiency retards chlorophyll formation, decelerates CO_2 assimila-

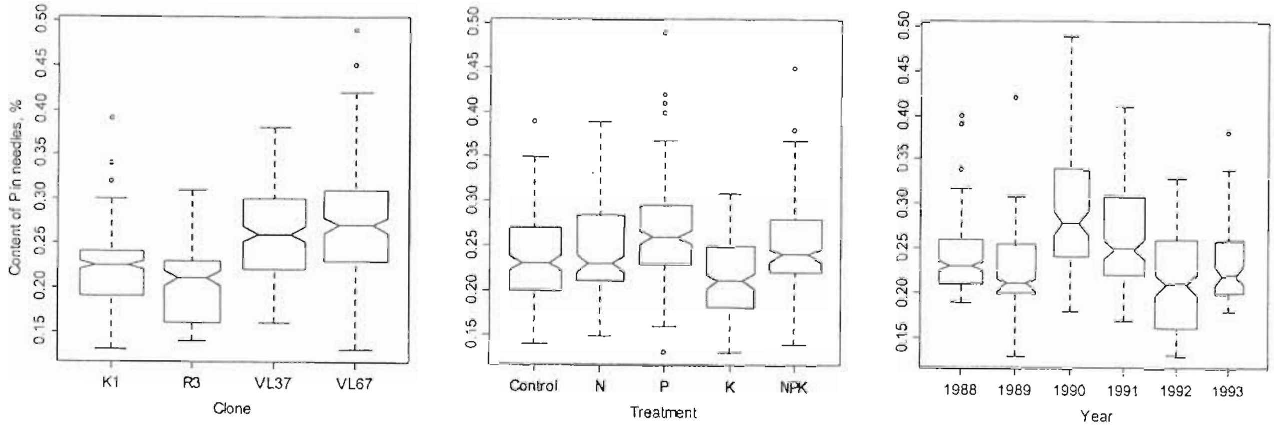

Figure 5. Boxplots of the P content in needles from different clones, treatments and measurement years

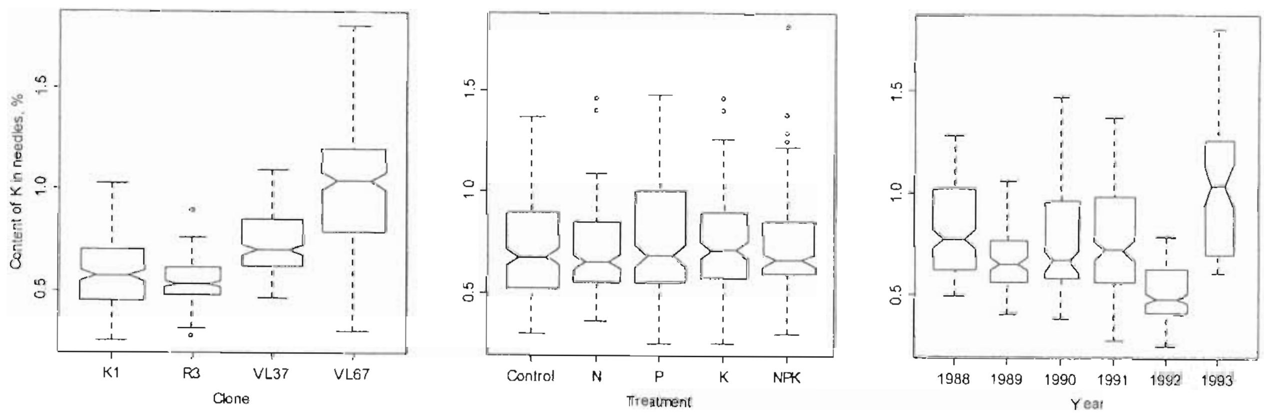

Figure 6. Boxplots of the K content in needles from different clones, treatments and measurement years

tion and leads to lower carbohydrate levels (Mohr, Scopfer 1995, Pihelgas 1983). It has been established that fertilization with calcined magnesite boosts the mineralization rate of soil organic matter (Jandl, *et al.* 2001). Based on our trial results, the mean needle Mg content was 0.18% and the factors contained in the model accounted for a mere 27% of the variance. The clone turned out to be the most significant factor (Figure 7); the effects of fertilization and the year as well as needle N and Ca content also proved reliable. Of clones, the progenies of VL37 evidenced the highest Mg content (0.22%) and those of K1 lowest (0.15%). Fertilizers, excluding potassium chloride, had a negative effect on needle Mg content. The maximum needle Mg content was observed in 1990.

Calcium is a nutrient necessary for plants, since it stimulates biochemical processes, including the biochemical activity of soil microorganisms (Miidla 1984). Based on our data, the mean needle Ca content was 0.51%. According to our research, needle Ca content depended on the clone, the year and fertilizers (Figure 8) as well as needle P and Mg content ($p<0.0001$). Distinctly different from the other clones was VL37, the grafts of which stood out for the highest needle Ca content (0.57%). As regards fertilization, addition of nitrogen fertilizer lowered graft needle calcium levels to 0.47%.

Needle nitrogen, phosphorus and potassium levels in seed orchards are usually high (Данусявичюс 1982). Fertilization has revealed no correlation between needle nutrient content and seed crop (Saarsalmi *et al.*, 1994); on the other hand, E. Mälkonen (1971) has found that spruce needle nitrogen and potassium content account for 40% of graft seed crop variance in a good seed year. Based on our data (Kurm, Kiviste 2001), potassium fertilizer leads to an increase in both needle K content and graft cone density.

Apart from the absolute nutrient content, another very important factor is nutritional balance. The ratio between nutrient elements is called the species geno-

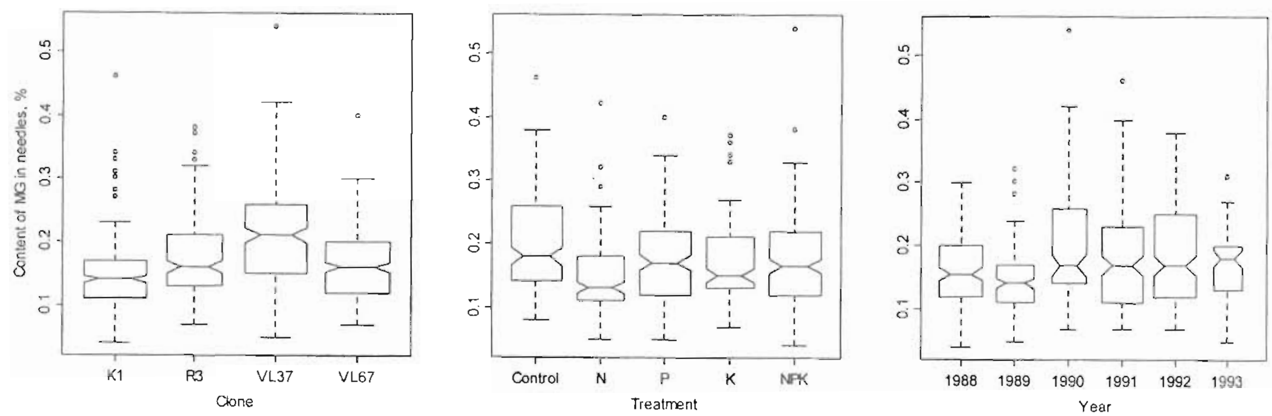

Figure 7. Boxplots of content of MG in needles from different clones, treatments and measurement years

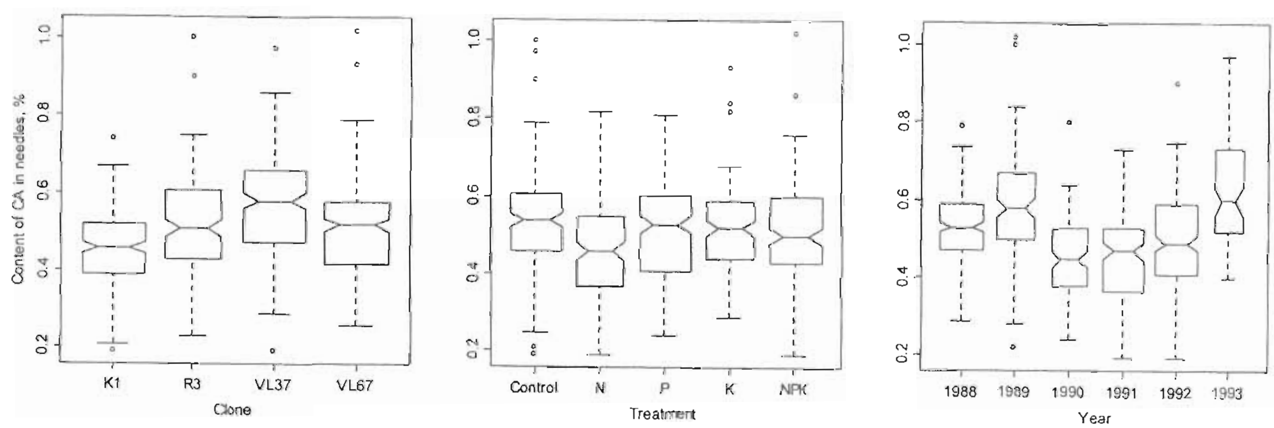

Figure 8. Boxplots of content of CA in needles from different clones, treatments and measurement years

typic ratio. It has been reported in the literature (Иванова, Лавриченко, 1980) that the above-mentioned ratio for spruce is 60:9:31, if N+P+K=100. Based on our research findings, the ratio for spruce proved to be 57:11:32. The spruce graft needle nutrient element ratios by trial variants, the year, and the clone have been reflected in Table 4. Fertilization with ammonium nitrate led to a substantial ($p<0.0001$) increase in needle N content while substantially ($p<0.0001$) decreasing the K content. Fertilization with superphosphate resulted in a substantial ($p<0.0001$) increase in needle P content and a decrease in needle N content ($p=0.037$). Application of potassium chloride raised needle K content ($p=0.0023$) and substantially reduced ($p<0.0001$) needle P content.

Fertilization trials rarely yield fully matching results, since their effect manifests itself in interaction with other factors, including the weather conditions of different years, the individualities of different grafts, etc. More accurate results may be obtained by establishing trials simultaneously using the same scheme in different places or different soils. Also significant is the duration of fertilizer action.

Conclusions

1. Spruce graft variables (needle length, weight of 100 needles, density of needles and the content of nutrient elements of needles) are influenced most considerably by the year, which has a significant effect on almost all the attributes addressed in this work.

2. The clone also has a significant effect on all the needle attributes.

3. Different fertilizers reliably influence graft needle nutrient element content as well as needle dimensions and needle weight.

- Ammonium nitrate increases needle weight, length and N content and reduces needle Mg and Ca content as well as, to a small extent, needle K content.

• Fertilization with superphosphate increases needle weight, length and P content while decreasing needle Mg content.

• Fertilization with potassium chloride increases needle K content; at the same time, however, potassium fertilizer reduces needle P content.

• Complete fertilizer increases needle length and weight as well as N and P content on the one hand yet reduces needle Mg content on the other.

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ВЛИЯНИЕ МИНЕРАЛЬНЫХ УДОБРЕНИЙ НА ХВОЮ ПРИВИТЫХ ДЕРЕВЬЕВ ЕЛИ ОБЫКНОВЕННОЙ В СЕМЕННОЙ ПЛАНТАЦИИ ПАУСКА, ЭСТОНИЯ

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Резюме

На основе измерений 1003 привитых деревьев ели обыкновенной анализируется влияние разных минеральных удобрений (азотного, фосфорного, калийного и полного) на размеры и вес хвои и на содержание в хвое азота, фосфора, калии, калции и магнезии. Выяснилось, что под влиянием аммониевой селитры увеличились длина и вес хвои и содержание N в хвое. Однако, с тем же содержание Mg и Ca в хвое уменьшилось. Применение суперфосфата увеличило длину и вес хвои и содержание P в хвое, но увеличило содержание Mg в хвое. Калийная соль увеличила содержание K, но уменьшило содержание P в хвое. Полное удобрение увеличило содержание N и P,но уменьшило содержание Mg в хвое.

Ключевые слова: *Picea abies*, семенная плантация, удобрение, хвоя, клон, фактор года.