Plant Investigations in the IUFRO Norway Spruce Provenance Experiments

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Introduction

For a long time the forest has rather been regarded and investigated in many countries as an ecologic unit than an ecosystem. Stability and survival are of vital importance for the forest ecosystem, whether it is a natural forest stand or a man-made one (ULRICH, 1990/1991). The main emphasis is laid upon the appropriate choice of tree species, that is, the tree species must find its satisfactory site conditions. However, beyond these, economic aspects should not be neglected either, meaning that ecologically feasible and in addition highly profitable tree species have to be selected for the given site. This is the interest of forest holders.

Similarly to most parts of Europe, the demands for timber are increasing in Hungary, too. Therefore attention has been focused on tree species that are able to produce high timber volume of favourable commercial value in a relatively short time. The Norway spruce (*Picea abies* L.) is such a species. The timber production potential of this species can be increased by suitable and well-planned forest tree improvement activities. The task we are confronted with is to establish swift-growing forest stands with Norway spruce, which can adapt to the hilly and mountainous geographical conditions of our country and its yield is valuable enough for the timber industry due to the favourable features of its wood.

In the frame of IUFRO (International Union of Forest Research Organizations) 1500 Norway spruce provenances were collected in 1958, from which 11 were Hungarian. The seeds were sown in the former BRD and the seedlings of 1100 provenances were distributed to several places.

The international Norway spruce provenance testing experiment was set up in Hungary in 1964-1968 at Gyöngyössolymos (NE-Hungary) in the forest sub-compartments of 58 B and C. The first results of this experiment were published by SZŐNYI & ÚJVÁRI (1970, 1975), ÚJVÁRI & ÚJVÁRI (1980) and ÚJVÁRI (1986).

Similar provenance testing experiments have been established in some European countries with the same experimental arrangement.

In Austria the provenance testing experiment is located in Klaus an der Pyhrbahn (IX. plot). Planning and implementation of the experiment were the responsibility of the Austrian Forest Research Institute, namely of its Institute for Forest Tree Breeding. The first results were reported by GÜNZL (1979).

Another testing area is in Bohemia, in the Bohemian-Moravian Central Mountains, near to Ledeè nad Sazavu. The experiment is coordinated by the Bohemian Forest Research Institute (Vyzkumny Ustav Lesniho Hospodarstvi a Myslivosti). Results were published earlier by VINS & VANCURA (1977, 1979).

The fourth testing area – situated in Hessen (Germany) – differs somewhat. It is tended to by the Hessische Forstliche Versuchsanstalt, Hann. Münden. It has been placed in the subcompartment Beberbeck 481A (Forstamt Reinhardshagen). The results were summarized by WEISGERBER et al. (1976, 1977, 1984).

Plant species can be characterized by variablility, which is due to their internal features together with the external effects. Morphological and physiological differences may arise by differences in nutrient supply, too. If the latter case can be proven, it is worth looking for the reasons and finding out whether these differences are suitable for a possible isolation of provenances within the species.

Considering the above-mentioned facts the following questions were aimed by our investigations:

– Is the nutrient content in the needles in itself – regardless of the site conditions – suitable for the isolation of provenances?

– What is the reliability level of nutrient supply categories for the sound nutrition of forest stands consisting of mixed provenances?

– Can the nutrient content data and their limits published in the literature be adapted to Hungarian conditions?

Material and Methods

In plot No. IX. of the Gyöngyössolymos experimental field 3-3 provenances were selected, which were partly superior to the mean of all trees, partly significantly worse than the mean. All the individuals of these provenances were sampled. Due to natural mortality and random arrangement, the number of trees by provenances is not identical. As a rule, 40-60 trees by plots were sampled. Provenances chosen were as follows: Nagykanizsa-Iharos (Hungary), Istebna (Poland), Turda-Virtopeni 34A (Romania), Geraasaag (Sweden), Mikkelin (Finland), Oberberg-Gries (Austria).

Some general data on the experimental sites and their soils are presented in Table 1.

Table 1

Some general data on the experimental sites and their soils

	Altitude above sea level, m	Annual precipitation, mm	Mean annual temperature °C
Austria (A): Klaus an der Pyhrbahn	458	1638	8.6
Bohemia (B): Dolni Kralovice/Stritez	390-400	640	6.9*
Hungary (H): Gyöngyössolymos	550	610	8.1
Germany (G): Beberbeck	250	818**	7.7

	Soil type	pH (KCl)	y_1	$CaCO_3$ %	H %	Clay %	T-value mmol/ 100 g	V % ***
A	strongly eroded brown rendzina	5.5-7.3	11	11–48	9.8	24-38	33-81	58-98
B	strongly leached brown forest soil with clay illuvations	3.4-4.6	6-30	-	6.2	18-37	18-37	31-55
H	brown foest soil with clay illuvations	4.1-4.8	8-24	-	4.5	19-27	19-27	41-68
G	brown forest soil with clay illuvations	2.9-3.9	8-35	-	2.3	23-37	23-37	7-43

* Mean temperature in the growing season: 13.2 °C; **more than 60% of the annual precipitation falls in the growing season; *** Percentage of saturation.

The sampling was carried out in November 1995, after the vegetation season on all four experimental sites. After cutting, the air-dried shoot samples were ground to small fractions, but not to dust-fineness.

The total nitrogen content was determined by the Kjeldahl method, while in case of the other elements the samples were first digested (HNO_3 and H_2O_2), Phosphorus, potassium, calcium, magnesium, and trace elements (Fe, Mn, Cu, Zn, Mo, B and Al) were measured with GBC INTEGRA XM inductively coupled plasma optical emission spectrometer. The experimental data were statistically evaluated with a SPSS-Windows-Version 6.0 program package. The evaluation was partly carried out at the Göttingen University and partly at the Sopron University. For the evaluation of various provenances on the same site and of the same provenances on different sites variance analysis and multiple factorial techniques were applied.

To get acquainted with the soil conditions soil profiles were dug and surveyed. In Bohemia, Germany and Hungary the soil type was brown forest soil with clay illuvations on loess or loessial loam, while the Austrian soil was strongly clayey and eroded brown rendzina on limestone. Physical features of the latter soil greatly differed from the others. Some important soil characteristics ot the experimental sites are presented (without the depth) in Table 1.

Regarding the most important soil characteristics and the nutrient supplying capacity of soils, the soil conditions of the experimental sites are not the same, by which the nutrient content in the soils may also differ. In the Austrian experimental field the unfavourable physical characteristics of the soil are limiting factors of the suitable growth of Norway spruce. This tree species requires well aerated soil conditions (SCHMIDT & VOGT, 1986) and this requirement has not been met by the very compact, structureless clay.

Results

Comparison of the various sites

The effect of the site on the nutrient content of Norway spruce needles was investigated for the means of the provenances. Calculation results can be seen in Table 2.

The results of plant analysis give evidence for the existing differences in N, P, K, Ca, Mg, S, Mn, Zn, B, Mo, Al of the Norway spruce stands and these differences can be justified on 95% probability level. Only Fe and Cu have not shown these differences on 95% probability level.

Most of the nutrients analyzed more or less accumulate in the needles due to the total influence of all site factors, indicating the different nutrient supply of the soils. At the Gyöngyössolymos experimental site there was a slight N-defi-

Table 2

Nutrient content (mg/kg) of Norway spruce needles at the four experimental sites (Data calculated from the means of tested provenances)

Nutrient	Austria	Bohemia	Hungary	Germany
N	15.5***	13.9**	11.8	12.7*
P	0.7	1.2**	1.0*	1.4***
K	1.7	5.5*	5.5*	6.9***
Ca	8.8*	11.2**	14.7***	6.1
S	1.9	3.5***	2.3*	2.0
Mg	1.6***	0.9	0.9	0.8
B	13.5*	7.4	24.9***	15.8*
Cu	3.9*	3.1	3.9*	4.3*
Fe	49.4*	43.9	47.3	43.1
Mn	398	958*	1843**	2391***
Zn	31.7**	18.0	77.1***	19.1

Note: * – significant difference on 95 % probability level ciency. On the Austrian field we can reckon with P and relative K deficiencies as the N/P and N/K ratios are big. There was no deficiency in the meso-elements Ca, Mg and S and in the trace elements Fe, Mn, Cu, Zn, B and Mo.

Comparison of the various provenances

The effect of various provenances on the nutrient content in needles were investigated, irrespective of the site conditions (Table 3).

Table 3

Nutrient contents (mg/kg) in 2-year-old needles of various Norway spruce provenances, irrespective of site conditions (Data calculated from the means of tested provenances)

Nutrient	Provenances+					
	05	28	35	38	81	98
N	13.5**	14.0**	14.4**	14.4**	12.3	12.3
P	0.93	0.95	1.2**	1.0	1.1	1.2**
K	5.2	5.3	5.8*	5.3	5.4	6.4****
Ca	11.0	11.0	10.0	11.1	10.6	9.9
Mg	1.0	1.0	0.9	1.0	1.0	0.8
S	2.6**	2.4	2.1	2.2	2.1	2.2
Mn	1246	1302	1501	1220	1420	1460
Cu	4.1**	3.8*	4.2**	2.9	3.5	3.6
Zn	42*	45*	27	51**	43	37
B	16	17	14	19	15	15

Note: Provenances: 05 – Nagykanizsa-Iharos; 28 – Istebna; 35 – Turda Virtopeni, 38 – Geraasaag; 81 - Mikkelin Mlk.; 98 - Obenberg-Gries; *: significant difference on 95% probability level

Based on the analyzed data the impact of provenances on some nutrient element contents can be proven. The development of the phytomass (diameter, size of phytomass) can be followed mainly by N and P contents. Provenances of better growth have significantly more N and P contents, and regarding the absolute quantity of these elements they are also superior. In spite of the different Ca content in the soils, it cannot be followed in the needles, only occasional differences can be demonstrated. The needles have nearly the same magnesium, sulphur, iron, manganese and boron contents. Of the trace elements, it is the Cu, Zn and Mo contents for which the differences are significant, but in general the provenances of better growth have higher Cu contents. On the basis of these investigations it is mainly the N, P, Ca and partly Cu, Zn and Mo contents by which the provenances can be isolated. This finding needs some further confirmation. Mg, S, Fe, Mn and B contents do not seem to be suitable for this purpose.

In the following the correlation coefficients of nutrients in the plants are analyzed. The results are given in Table 4.

There was no close correlation between the soil investigation data and the nutrient concentrations in the plant samples. The best correlation was between

Table 4

Correlation coefficients of plant nutrients

	N	P	K	Ca	Mg	S	Mn	Zn	B
N	-								
P	-0.22	-							
K	-0.16	0.58	-						
Ca	-0.20	-0.21	-0.28	-					
Mg	0.11	-0.11	-0.17	0.05	-				
S	-0.15	0.18	0.02	0.24	0.06	-			
Mn	-0.41	0.46	0.39	0.15	-0.22	0.01	-		
Zn	-0.30	-0.26	-0.11	0.55	0.02	-0.07	0.20	-	
B	-0.30	-0.04	0.14	0.25	0.04	-0.06	0.34	0.54	-

P and K (r = 0.58), Ca and Zn (r = 0.55) and Zn and B (r = 0.54), respectively. However, these only demonstrate tendencies and do not prove a close relation between them. Close correlation among Ca, Mg, Zn was found in the needles of Norway spruce by ALDINGER (1987), ZÖTTL & MIES (1983) and NEBE & HERMANN (1987). In their investigations increasing earth metals were coupled with increasing Zn and P and decreasing Mg.

The principal component analysis was used to detect the relations among the nutrient elements in the needles. On the basis of this analysis groups could be formed from the nutrient elements, as follows: The model arranged the nutrient elements Mn, Al, K, P, N into one factor, all with positive sign (with the exception of N), while Zn, Ca, B with positive and N with negative sign into the other group. The arrangement into two factors confirms the fact that provenances in their entity reflect the nutrient supply of the given site. The nutrient elements can be seen in the element-space diagram in Figure 1.

Factor 2 incorporates the elements, the easily soluble quantity of which are best reflected by the nutrient status of the needles. The closest correlation between nutrient contents of the soil and that of needles was found in this case. The negative sign of nitrogen and phosphorus shows that the levels of N and P decrease, if the aforesaid nutrients were taken up in higher quantities. In this factor there is a strict P–Zn and P–Ca antagonism. The presence of Mn, Al, K and P with big weight shows that the ground of isolation is accompanied by Mn and Al uptake in high quantity and their accumulation in the plants. This is a frequent symptom in acidic soils.

The quantity of K depends on the quality of basic rock, the reaction of soil is a less determinant factor. On the investigated sites the P content is high in soils in which it may not at all be expected according to soil reaction. This fact can be explained by the former agricultural use of the fields in Germany and Bohemia and the P used as fertilizer had been built into the local nutrient cycle. In these places the exchangeable and easily soluble Ca and Mg ions are only

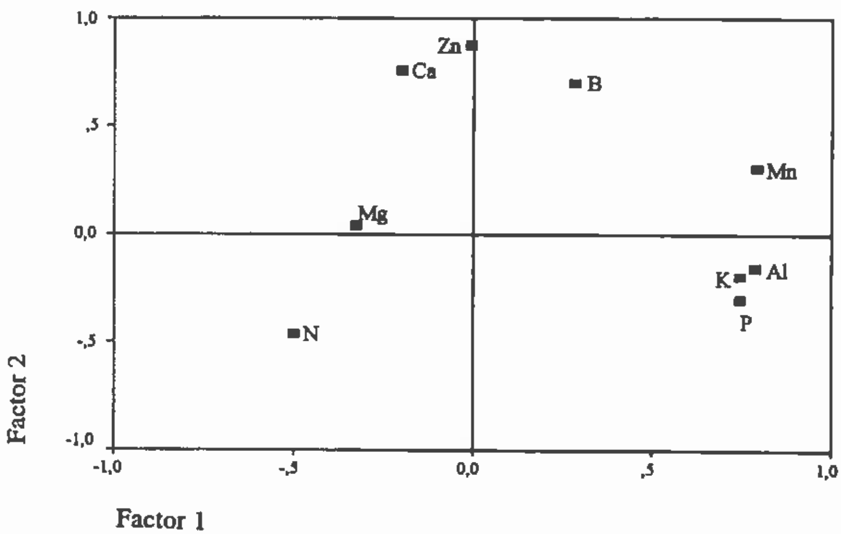

Figure 1
Plant nutrient elements as the function of factors 1 and 2

present in small amounts, therefore K uptake is not hindered, thus, the high K uptake may depress that of Ca and Mg.

GARTEN (1978) surveyed – by principal component analysis – the relationships among nutrient elements in the case of 110 plant varieties. In his investigations the similar biochemical properties of the elements present in the processes of cell-level gave the ground for group formation. BUNDERSON et al. (1985) used factor analysis for the analysis of leaf nutrients. They wanted to study the interelationships between environmental variables and the soil, which can be taken as preindicators for leaf nutrient concentration. WENTWORTH & DAVIDSON (1987) – with principal component analysis – demonstrate how plant populations can be isolated in a defined space by mineral element concentrations.

Summarizing our findings it seems that the elements arranged into factors mainly reflect the reaction and nutrient status of soil. The sites differ to a considerable extent in their soils' Zn, Ca, B, P, K, Mn and Al contents.

Discriminance analysis was used for the allocation of various provenances in the „nutrient element space" by the discriminance function. By this means we tried to find out whether plant analysis data – as input data – are sufficient to isolate the provenances. That is, whether the description of nutrient status can be a firm base for the identification of provenances or even for their determination.

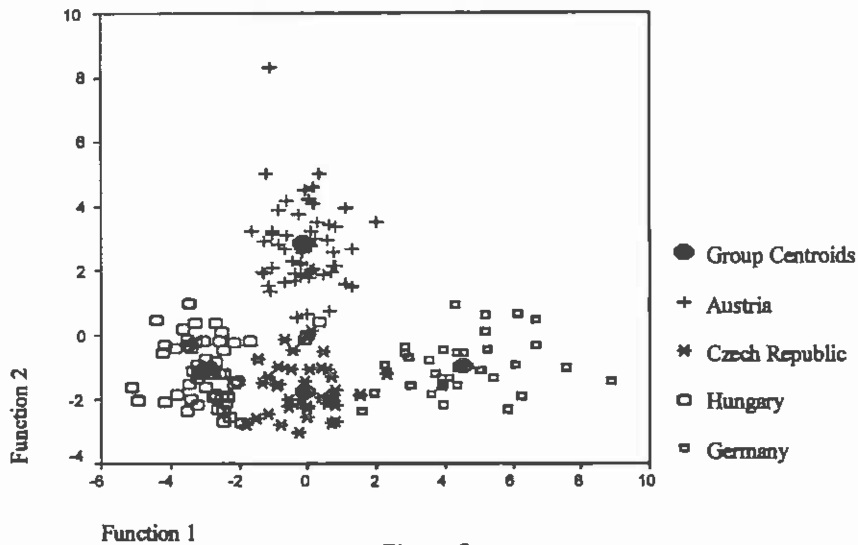

Figure 2
Values of canonical discriminance function by experimental sites

Discriminance analysis by sites seemed promising. On ground of such analysis 93.9% of 196 cases were grouped correctly. This has given evidence on the reliability of discriminance function and the exactness of the whole procedure. On Figure 2 the discretely isolated sites are shown, which were represented on the basis of two discriminance functions and the nutrient contents in the plants. All four sites are well limitable and the group centres are relatively far from each other.

Discriminance analysis was conducted by grouping the provenances, too. On Figure 3 the provenances are shown on the basis of the values of two discriminance functions.

As shown by Figure 3, function values could be arranged into two groups by provenances of better and poor growth. Of the better growing provenances those of Nagykanizsa-Iharos and Istebna are close to each other, and somewhat isolated from them is that of Turda-Virtupeni. In the poorly growing group there are two Scandinavian provenances with similar properties, and the third, the high mountains provenance from the Alps is isolated from the previous two. Genetically the Finnish and Swedish provanences are more closer, as they are on plains, while the Austrian is at the higher site of the Alps.

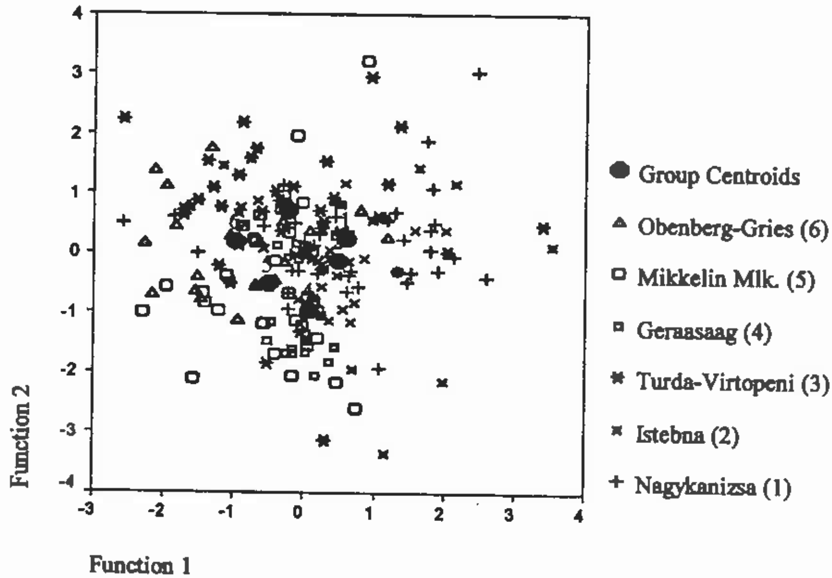

Figure 3
Demonstration of the values of canonical discriminance function by provenances

GARTEN (1978) applied multiple factorial discriminance analysis to demonstrate how various plant varieties take place in an „elementary" hyperspace. WENTWORTH & DAVIDSON (1987) came to the conclusion – by discriminance analysis (plant populations were treated as independent variable) – that the populations represent fairly discrete unities according to their leaf nutrient concentration. The site effect was also well demonstratable. On saline soils in China TÓTH et al. (1995) determined the accuracy to which soil variables like pH and EC can be predicted. Discriminance analysis showed that the correlation between soil and grassy vegetation is very close. TÓTH & KERTÉSZ (1996) elaborated a new mapping technique for saline soils on the basis of the distribution of vegetation units.

Summary

Soils under the four provenance testing experiments with Norway spruce (*Picea abies* L.) differed, including their nutrient supplying capacity. Significant differences were demonstrated in the N, P, K, Ca, Mg, S, Mn, Zn, B, Mo, Al contents of the Norway spruce stands, irrespective of their provenance. Only Fe and Cu contents were not in accordance with characteristics of the site.

The provenance effect (regardless of the site conditions) was shown by some of the nutrients. Provenances performing the best diameter and phytomass productions had the highest N and P contents in the needles. Provenances can be isolated first of all on the basis of their N, then by P and Ca, and partly by their Cu, Zn, Mo contents. Mg, S, Fe, Mn and B contents are not suitable for this purpose.

Based on the principal component analysis, first of all the nutrient contents in plants can be grouped around a background variable. The discriminance analysis demonstrated the site differences. In the discriminance function space formed needle nutrient concentrations, the provenances can be arranged into two groups.

Provenances of better growth can be arranged into group 1, while those of poor growth into the second. Plant investigations, together with discriminance analysis may be suitable for isolating provenance groups.

The limit values for nutrient supply influencing the growth potential of forest stands (diameter, height) published in the literature may be adapted to Hungarian conditions, with the exception of N and P, which are present in the highest concentration in needles. Under the Hungarian site conditions N and P concentrations may be low for attaining optimal growth of trees.

Nutrient deficiencies or even toxicity can be proven with the contemporary analysis of one- and several-year-old needles, thus, this is worthy of trial for monitoring the health conditions of Norway spruce forests.

It is recommendable to Hungarian forestry practice that plant and soil nutrient analysis should be introduced when planning the nutrient supply of energy forests or mini-rotation forestry plantations.

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