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HENRYK FOBER AND MACIEJ GIERTYCH

Variation among Norway spruce of Polish provenances in seedling growth and mineral requirements

INTRODUCTION

Long term provenance studies on Norway spruce have shown the species to have a considerable racial differentiation within the European part of its range. The differences usually reported concern the tree height or other growth parameters, that are of economic interest. Several Polish provenances have been included in the international experiments organized by IUFRO in 1938. These were Istebna from the Silesian Beskids, Białowieża, Brody * from the Nysa valley and Radom. The last one however is believed to be not indiginous. Only these Polish provenances have been extensively tested: Istebna and Brody on 13 sites in various parts of Europe and North America, Białowieża on only 3 sites and Radom on 7 (Veen 1953). Baldwin (1967) who summarized the literature so far published from this IUFRO experiment reports that all 4 Polish provenances are among the upper third of those used, while Istebna is excelled only by the Rumanian provenance Crucea.

In German experiments performed on a national scale before the II world war also some Polish provenances have been included, namely Borki *, Stronie Śląskie * and Piechowice *. The population from Stronie Śląskie proved to be among the best in Turyngia, Württemberg and Saxony (Troeger 1958, Schönbach 1957) while in Bavaria it grew rather poorly (Rubner 1957). The population from Borki grows well in Bavaria, Saxony and Württemberg but poorly in Turyngia (Troeger 1958, Schönbach 1957). The Piechowice population grows feebly in all the four regions (Troeger 1958). Generally therefore spruce races from Poland are worth closer scrutiny.

* In German literature the provenances are referred to as Pförten, Borken, Seitenberg and Petersdorf respectively for Brody, Borki, Stronie Śląskie and Piechowice.

Table 1

Geographic coordinates of provenances used in the study

Provenance No.	Locality	Long.*	Lat.	Alt. m
S–16–96	Brody	14°53′	51°42′	80
S–15–98	Kowary	15°52′	50°48′	625
S–03–99	Istebna	18°52′	49°33′	630
S–03–100	Wisła	18°56′	49°37′	650
S–04–101	Rycerka	19°00′	49°32′	530
S–04–103	Nowy Targ	20°07′	49°31′	1000
S–09–104	Wetlina	22°30′	49°08′	700
S–10–106	Garbatka	21°36′	51°31′	130
S–10–107	Bliżyn	20°42′	51°05′	320
S–14–109	Konstancjewo	19°08′	53°11′	90
S–07–110	Iława	19°34′	53°39′	116
S–07–111	Nowe Ramuki	20°34′	53°39′	143
S–07–112	Sadłowo	21°06′	53°55′	143
S–11–113	Myszyniec	21°09'	53°22′	120
S–11–114	Sławki	21°07′	53°03′	130
S–07–115	Borki	22°05′	54°06′	155
S–07–116	Przerwanki	22°04′	54°08′	150
S–01–117	Gołdap	22°24′	54°20′	150
S–01–118	Suwałki	23°07′	53°59′	170
S–01–119	Augustów	23°11′	53°54′	130
S–01–120	Białowieża	23°47′	52°40′	160
S–01–121	Zwierzyniec	23°47′	52°43′	160
S–05–122	Międzyrzec	22°57′	52°03′	154
S–15–125	Stronie Śląskie	16°55′	50°18′	870
S–04–133	Dolina Chochołowska	19°48′	49°13′	1400

In selecting provenances for the present series of experiments an effort was made to obtain samples from all the main or most interesting spruce regions in Poland. The seeds were collected from 25 localities (fig. 1, table 1). An effort was made also to obtain seed from all the localities already represented in earlier trials in order to be able in the future to tie our results with the international ones. Thus our studies include Istebna, Brody, Białowieża, Stronie Śląskie and Borki. Our Bliżyn population originates from a locality close to the Radom one, but is definitely indiginous. Also Piechowice and Kowary are very close to each other.

The studies reported in this paper have been conducted in the greenhouse and concern seedlings after one growing season. Thus they can be considered to be an early test for the large scale field experiments that have been established from the same material (Giertych 1970) and that will, it is hoped, yield in the future useful informations about racial differentiation of Polish spruce in characters of economic importance.

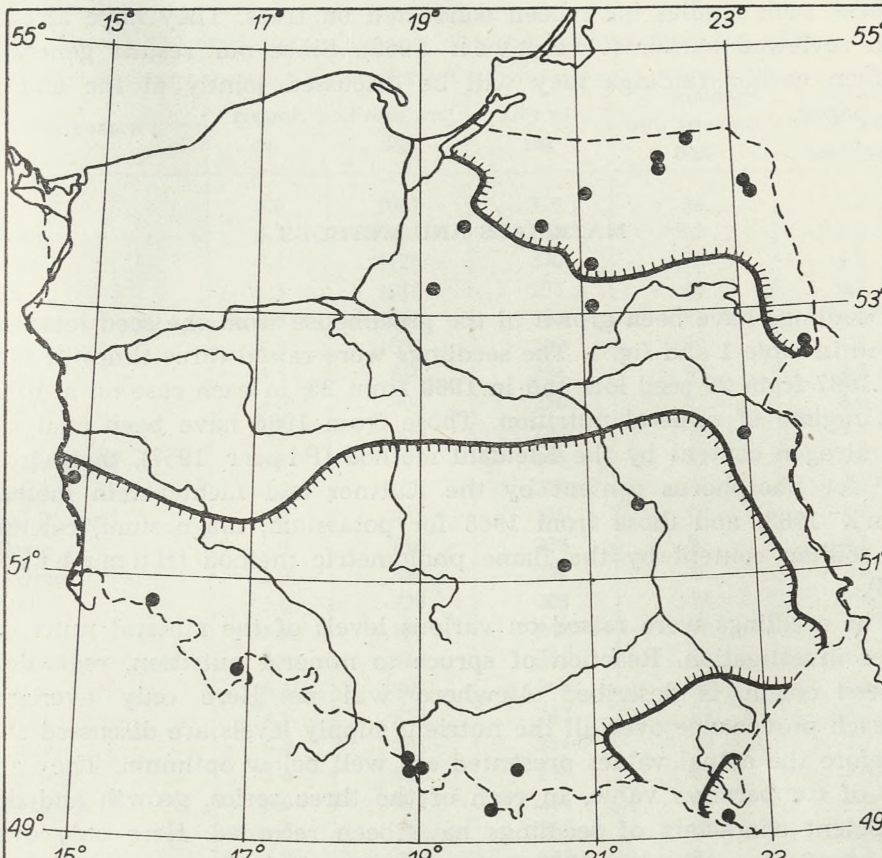

Fig. 1. The range of *Picea abies* (L.) Karst. in Poland and the location of the sites where seeds were collected

It may well be that some of our early results reported here will correlate with those that will become available later. This will show to what extent time and effort can be saved by studying seedlings under controlled conditions and extrapolating their performance to desired informations about older trees.

The seedling characters selected for analysis in our studies pertain to growth, development and content of major mineral elements. Racial differences in mineral requirements and metabolism of plants have been known to exist in agricultural and pomological crops for quite some time. For example varietal differences in nitrogen concentration under identical culture conditions have been reported for tea, strawberry, apple, rice, wheat, corn and Citrus sp. (E p s t e i n and J e f f e r i e s 1964). Much of these differences can be attributed to variations in root surface area rather than to absorption or transport difficulties.

Few such studies have been conducted on trees. They have already been reviewed earlier (Giertych 1969). Since our results generally confirm earlier findings they will be discussed jointly at the end of this paper.

MATERIALS AND METHODS

Seedlings have been grown in the greenhouse from the seed lots described in table 1 and fig. 1. The seedlings were raised three times in 1966 and 1967 from 20 seed lots and in 1968 from 25, in each case on a different regime of mineral nutrition. Those from 1966 have been analysed for nitrogen content by the Kieldahl method (Piper 1957), those from 1967 for phosphorus content by the Kuttner and Lichtenstein method (Fink 1963) and those from 1968 for potassium, magnesium, calcium and sodium content by the flame photometric method (Humphries 1956).

The seedlings were raised on various levels of the mineral nutrients under investigation. Reaction of spruce to mineral nutrition, regardless of seed origin, is described elsewhere will be. Here only averages for each provenance over all the nutrient supply levels are discussed and therefore the actual values presented are well below optimum. They are only of comparative value. In each of the three series, growth and development characters of seedlings have been recorded. Here only average results from the last 1968 series are presented. These correlate well with the earlier ones and are most reliable because they are based on the largest number of seedlings.

All results have been subjected to variance and regression analyses.

RESULTS

In table 2 average values of the growth and developmental characters are presented. All the characters defining growth correlate very well with each other. This is also true for dry weight of plant parts (roots, stems, leaves), for the number and length of lateral shoots and for the number of buds per seedling. Thus all differences between provenances in these characters can be considered as being a function of growth. Also it was found that there is a highly significant positive correlation ($r = 0.50$) between the average seedling dry weight and the average heights of 3 year old seedlings in nursery conditions, reported elsewhere (Giertych 1970).

Table 2

Growth and development characters of spruce seedlings of various origin

Provenance	Height cm	Fresh wt. mg	Dry wt. mg	% seedlings with terminal bud	No. of buds per seedling
Brody	6.6	1061	313	94	4.2
Kowary	6.3	1001	284	92	4.6
Istebna	7.2	1126	330	92	4.1
Wisła	6.5	1016	293	88	3.7
Rycerka	6.5	1061	302	91	4.2
Nowy Targ	6.2	1007	289	90	4.2
Wetlina	5.3	810	234	95	3.3
Garbatka	6.0	904	256	97	4.0
Bliżyn	6.3	1006	288	93	3.9
Konstancjewo	6.8	1103	315	92	4.8
Iława	6.5	1022	289	91	4.1
Nowe Ramuki	6.0	875	241	92	3.5
Sadłowo	5.6	816	233	91	4.1
Myszyniec	5.9	840	231	88	3.6
Sławki	5.0	728	205	94	3.6
Borki	5.8	881	249	90	3.8
Przerwanki	5.9	916	261	89	3.8
Gołdap	6.1	903	264	94	4.6
Suwałki	6.1	857	247	83	3.3
Augustów	6.2	891	254	88	3.7
Białowieża	5.6	828	238	89	3.4
Zwierzyniec	6.0	911	266	92	3.6
Międzyrzec	5.8	918	263	92	3.7
Stronie Śląskie	6.1	1000	277	93	4.3
Dolina Chochołowska	4.9	716	195	95	3.3

On the other hand the percentage number of seedlings with terminal buds does not correlate with any other character of the provenances. In foliage colour, only the seedlings from Dolina Chochołowska are oustanding in that they are distinctly darker.

In table 3 the content of mineral nutrients expressed as a percentage of the average is presented. Provenance differentiation in mineral content was highly significant except for phosphorus for which element the differentiation was significant only on the 0.10 level and for magnesium where no provenance differentiation was found. Correlation of these characters with growth, geographic parameters and between themselves are represented in fig. 2.

Average seedling dry weight for the provenances was found to be correlated with the weight of seeds from which the were raised. Nitrogen concentration in the seeds was negatively correlated with the nitrogen concentration in the seedlings. Also Mg% in seeds was inversly correlated with P% in seedlings and P% in the seeds with Ca% in seed-

Table 3

Content of mineral elements in seedlings of various origin expressed as percentage of the mean

Provenance	N	P	K	Mg	Ca	Na
Brody	84.4	91.7	108.5	97.2	89.5	105.4
Kowary	102.8	92.1	100.2	105.4	98.8	109.2
Istebna	95.0	105.1	110.2	102.1	88.9	125.2
Wisła	–	107.9	88.6	97.2	100.9	117.6
Rycerka	93.6	116.2	100.2	101.3	103.3	105.4
Nowy Targ	–	102.0	100.9	96.4	97.4	105.4
Wetlina	119.1	109.5	91.2	96.4	100.5	87.2
Garbatka	–	–	96.4	100.1	97.8	107.7
Bliżyn	95.0	102.0	102.7	98.9	100.2	112.3
Konstancjewo	96.5	96.0	109.7	96.8	101.2	116.8
Iława	93.6	83.0	97.8	94.8	97.4	116.1
Nowe Ramuki	–	107.1	98.8	106.2	100.5	90.3
Sadłowo	–	–	99.2	100.5	102.9	88.8
Myszyniec	102.1	88.9	97.8	102.5	95.7	97.1
Sławki	97.2	–	97.0	103.8	107.0	88.8
Borki	103.5	–	100.2	98.9	105.3	91.0
Przerwanki	103.5	–	95.8	103.8	101.6	108.5
Gołdap	97.9	101.2	100.7	99.3	100.9	91.8
Suwałki	92.2	101.2	100.0	98.1	94.7	92.6
Augustów	91.5	104.3	96.8	102.1	105.7	99.4
Białowieża	94.3	98.4	95.8	101.3	100.5	94.1
Zwierzyniec	100.0	91.7	96.6	97.6	96.4	79.7
Międzyrzec	96.5	92.9	102.6	91.9	98.8	95.6
Stronie Śląskie	95.0	97.2	106.5	102.5	101.2	94.8
Dolina Chochołowska	141.8	111.9	106.2	105.0	112.5	78.9

lings. Ca% in seedlings was also positively correlated with Na% in the seeds.

There were numerous correlations between mineral concentrations in the seedlings and cone characters. Na% together with seedlings dry weight with which it is strongly correlated (fig. 2) seems to be correlated with the same cone shape characters. On the other hand P% and N% correlate inversly with these characters. K% is inversly correlated with cone and cone scale size characters (fig. 3).

DISCUSSION

The provenance differentiation in respect of growth characters generally follows the observations reported earlier for the first and second experimental series (Giertych and Fober 1967, Fober and Giertych 1968, 1970). The best growth was demonstrated by seedlings from Istebna. Those from neighbouring Wisła and Rycerka are also among the best. Of special interest are the provenances Brody and Konstancjewo. The seedlings had very high dry weights and the populations though separated geographically by a large spruceless area (fig. 1) are very akin in cone morphology (Chylarecki and Giertych 1969).

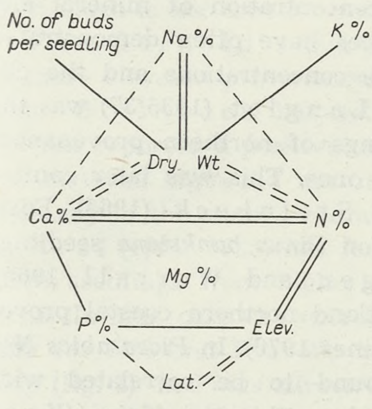

Fig. 2. Significant correlations between seedling characters and geographic coordinates. Double lines indicate significance at 0.01 level and a single line at 0.05 level. Continuous lines indicate positive correlations and broken lines negative correlations

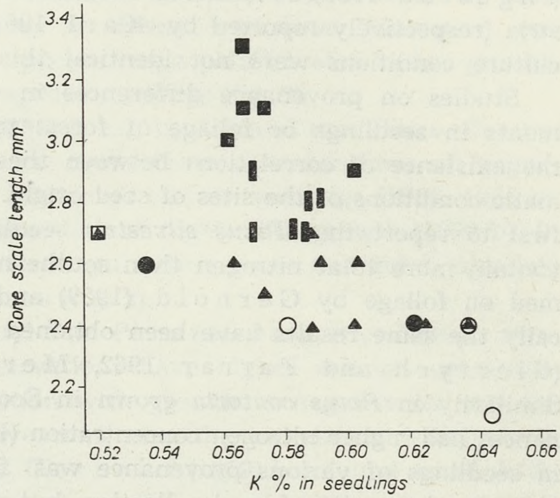

Fig. 3. Correlation of potassium concentration in the seedlings with the length of cone scales. The symbols for the groups of populations are as in Chylarecki and Giertych (1969)

Exceptionally poor growth has been displayed by seedlings from the High Tatras (Dolina Chochołowska). Generally spruce from regions tested in earlier field provenance experiments (Istebna, Brody, Białowieża, Bliżyn (nr. Radom), Stronie Śląskie, Kowary, Borki) gave satisfactory seedling growth, indicating that the choice of seed origins for the earlier experiments was well made. However judging from seedling size there are many more spruce areas in Poland, whose races are just as good and therefore merit popularization.

The correlation of seedling growth with seed weight is not a very close one ($r = 0.46$) because some provenances, notably Dolina Chochołowska, do not fit the pattern. However such correlations are normal for spruce. They are believed to be caused by provenance differences rather than by progeny differences within a stand (Ruden 1963). It appears that spruce races characterized by better growth are also characterized by heavier seeds (endowment of zygotes related to maternal affluence) though not consistently richer in any of the macroelements.

The percentage of dry weight in the fresh weight is a character that has been reported as differentiated geographically. It increased with latitude for pine (Langlet 1936/7) and for spruce (Langlet 1960). We have not confirmed this, and judging from literature the trend could be opposite. Working on seedling material the value was 25% in Sweden (Ingestad 1959) 30% in our Polish material and 39% or 40% in Austria (respectively reported by Karl 1961 and Holzer 1966). Since culture conditions were not identical this trend could be an artefact.

Studies on provenance differences in concentration of mineral elements in seedlings or foliage of forest trees have often demonstrated the existance of correlations between these concentrations and the climatic conditions of the sites of seed origin. Langlet (1936/37) was the first to report that *Pinus silvestris* seedlings of northern provenances contain more total nitrogen than southern ones. This was later confirmed on foliage by Gerhold (1959) and Steinbeck (1965). Basically the same results have been obtained on *Pinus banksiana* seedlings (Giertych and Farrar 1962, Mergen and Worrall 1965). Similarily in *Pinus contorta* grown in Scotland northern coastal provenances had higher nitrogen concentration (Lines 1970). In *Picea abies* N% in seedlings of various provenance was found to be correlated with altitude of the site of seed collection, but only within the Alpine (Kral 1961) and Sudeto-Carpathian (Giertych and Fober 1967) parts of the species range and not in the lowland spruce of NE Poland, though the. correlation holds for the whole material studied (fig. 2).

In all these studies there are indications that the better growing trees are the ones with lower N% (Gerhold's and Steinbeck's data are compared respectively with information on growth published elsewhere by Wright and Baldwin 1957, Wright and Bull 1963). Our studies confirm this (fig. 2).

Concentrations of phosphorus in *Pinus banksiana* seedlings are positively correlated with longitude and latitude of the site of seed origin (Mergen and Worrall 1965). In *Pinus silvestris* Steinbeck (1965) has not found any definite trends in P% but of the five provenances he has studied the extreme values were high for the one from the Urals and low for the one from Spain. These two provenances were also extreme in longitude and almost so in latitude. In *Picea abies* Kral (1961) has also shown that seedlings from more elevated provenance have higher P%. Our results confirmed this (fig. 2). The same trend was observed for *Pinus contorta* by Lines (1970). Similarily as with nitrogen concentration P% usually goes parallel with poorer growth.

The correlations of potassium concentrations with the site of seed origin are much less obvious. In *Pinus banksiana* there is a slight indication that the seedlings of southeastern provenances have higher K% thant the north western ones (Mergen and Worrall 1965). Gerhold (1959) and Steinbeck (1965) have not found any racial differences relative to geography in K% in *Pinus silvestris* nor have Kral (1961) or we (fig. 2) found any in *Picea abies*. In *Pseudotsuga menziesii* on the other hand Kral (1965) has shown that seedlings of coastal provenances had higher foliar K% than those from more elevated localities. The same is true for *Pinus contorta* in Scotland (Lines 1970). In these cases as well as in that reported for *Pinus banksiana* (Mergen and Worrall 1965) higher K% appears to go parallel with better growth. That much is also true for our spruce seedlings (fig. 2).

From Gerhold's data (1959) it can be deduced that *Pinus silvestris* of more elevated provenances has lower foliar concentrations of magnesium. Steinbeck has not confirmed this on seedlings (1965, 1966 a), but has reported a positive correlation of Mg% with growth (1966 b). In our material Mg% did not differentiate provenances nor did it correlate with any of the studied characters (fig. 2).

Kral (1961, 1965) has found that *Picea abies* and *Pseudotsuga menziesii* seedlings from higher elevations have higher calcium concentrations. In this case the correlation with growth is negative as was the case for N% and P%. We have confirmed the correlation with growth only (fig. 2). In *Pinus silvestris* Gerhold (1959) has found racial differences in foliar Ca% but this was not correlated with any geographic parameter and the negative correlation with growth was slight.

In the studies reviewed above only Steinbeck (1965) has investigated Na% in the foliage of *Pinus silvestris*. Generally lower Na% was found in less intensly growing seedlings. The same was confirmed for spruce in our material (fig. 2).

The positive correlation of Ca%, N% and P% with each other and negative with dry weight (fig. 2) suggest that fast growing seedlings economically utilize these elements and that growth dilutes their concentrations. On the other hand K% and Na% are correlated positively with growth suggesting that either active absorption of these elements is stimulated by growth or that growth is stimulated by their high internal concentration (extension growth requires high turgor). Since extension growth results in increased fresh weight rather than dry weight, and the correlation of K% is better with fresh weight than with dry weight, the latter explanation appears to be the valid one.

One of the highest magnesium concentrations was found in seedlings from Dolina Chochołowska (table 3), those that had the darkest foliage colour, suggesting that the inherent ability to accumulate more magnesium is expressed in higher chlorophyll content.

All the correlations of seedling characters with morphology of cones add little to our informations about the groups of populations. The genotypic data appears to be in a somewhat different dimention than the phenotypic variability. The grouping of spruce populations proposed on the basis of cone morphology (Chylarecki and Giertych 1969) is supported by the (phenotypic) data on seeds (Fober and Giertych 1971) but not by the data on seedlings (genotypic) The K% in seedlings though correlated inversly with cone scale length (the best cone character for differentiating populations) does not help in defining the groups of populations (fig. 3) as did K% in the seeds.

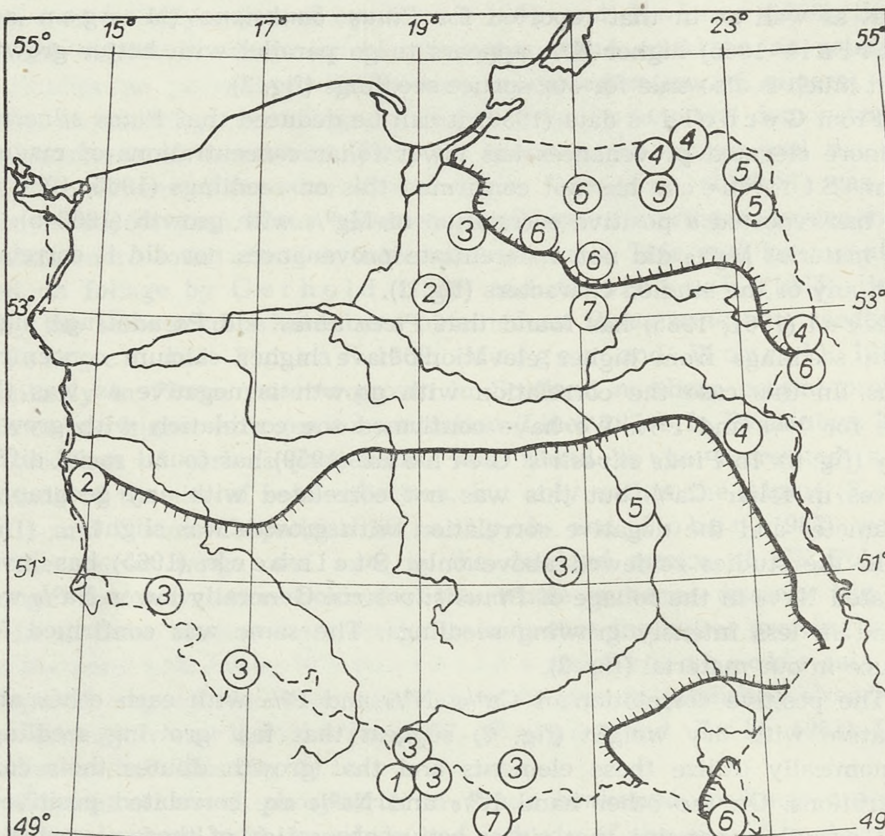

Fig. 4. Groups of spruce provenances, numbered 1 - 7 from the best growing to the worst, as determined by a Duncan test on the seedling dry weight character, plotted onto a map of spruce distribution in Poland

If we were to group the provenances on the basis of genotypic characters other groupings would be obtained. Using the Duncan test on total dry weight, the character that has best differentiated the provenances (highest value of F in the variance analysis), 7 groups were obtained. These are plotted on the map in fig. 4. Generally the best growing seedlings (groups 1 - 3) came from the south, medium ones (4 - 5) from the north east and the worst (6 - 7) from the north east and from the high altitudes in the south.

SUMMARY

Seedlings of 25 *Picea abies* Karst. provenances have been grown in greenhouse conditions under controlled mineral nutrition. The seedlings were scored for growth and development characters and their internal concentrations of nitrogen, phosphorus, potassium, magnesium, calcium and sodium was measured. It was found that the best growing seedlings were raised from seeds collected in the montane and submontane region of Poland as well as in the valley of river Nysa and in the outlier in Konstancjewo (fig. 4). The poorest growing seedlings came from the High Tatras. Many more Polish provenances deserve the renown of those that have been tested in international experiments. The concentration of nitrogen, phosphorus and calcium in the seedlings was correlated positively with each other and negatively with seedling dry weight (fig. 2). This suggests that fast growing seedlings economically utilize these elements and that intensive growth results in a dilution of these concentrations in the seedlings. K⁰/₀ and Na⁰/₀ in the seedlings are positively correlated with growth characters, particularily fresh weight, suggesting that higher concentrations of these elements stimulate extension growth. Groups of populations suggested on the basis of cone morphology (phenotypically) are not recognizable on the basis of genotypic characters of seedling growth and mineral content.

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Institute of Dendrology and Kórnik Arboretum
Kórnik nr. Poznań

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HENRYK FOBER I MACIEJ GIERTYCH

Zmienność świerka (Picea abies Karst.) polskich prowieniencji w cechach wzrostowych siewek i w zapotrzebowaniu na sole mineralne

Streszczenie

Siewki 25 polskich prowieniencji świerka *Picea abies* wyhodowano w szklarni w warunkach kontrolowanego żywienia mineralnego. Oceniono cechy wzrostowe i rozwojowe siewek oraz pomierzono zawartość w nich azotu, fosforu, potasu, magnezu, wapnia i sodu. Stwierdzono, że najlepiej rosnące siewki pochodzą z terenów podgórskich i górskich, jak również z doliny Nysy i ze stanowiska wyspowego w Konstancjewie (ryc. 4). Najgorzej rosnące siewki pochodzą z Wysokich Tatr. Wiele polskich prowieniencji zasługuje na podobny rozgłos, jaki uzyskały prowieniencje wypróbowane już w doświadczeniach międzynarodowych. Stężenia azotu, fosforu i wapnia w siewkach były skorelowane ze sobą pozytywnie, a negatywnie z suchą masą siewek (rys. 2). To sugeruje, że szybko rosnące siewki ekonomicznie wykorzystują te pierwiastki, czyli że przy intensywnym wzroście ich stężenie w siewkach ulega rozcieńczeniu. Stężenia potasu i sodu są pozytywnie skorelowane z cechami wzrostowymi, szczególnie ze świeżą masą siewek sugerując, że wyższe stężenia tych pierwiastków stymulują wzrost wydłużeniowy. Grupy populacji wydzielone na podstawie cech morfologicznych szyszek (fenotypowo) nie dają się zidentyfikować na podstawie cech siewek i ich mineralnej zawartości.

ХЕНРЫК ФОБЕР И МАЦЕЙ ГЕРТЫХ

Изменчивость Picea abies (L.) Karst. Польши по росту сеянцев и нуждаемости их в минеральных солях

Резюме

Сеянцы ели из 25 польских местонахождений выращивались в оранжерее в условиях контролируемого минерального питания. Изучались особенности их роста и развития и определялось содержание азота, фосфора, калия, магния, кальция и натрия. Установлено, что лучше всего растут сеянцы, происходящие из горных и подгорных районов, из долины Ниссы и из островного местонахождения в Констанцеве (рис. 4). Хуже всего растут сеянцы из Высоких Татр. Ели, происходящие из многих польских местонахождений, заслуживают такой

же известности, какую приобрели популяции, прошедшие международное испытание. Концентрации азота, фосфора и кальция в сеянцах положительно коррелируются между собой и отрицательно — с сухой массой сеянцев (рис. 2). Можно предположить, что более быстро растущие сеянцы экономичнее используют эти элементы и что при их интенсивном росте концентрация последних падает. Содержание же калия и натрия положительно коррелируется с интенсивностью роста, особенно с увеличением сырой массы сеянцев. По-видимому, высокая концентрация этих элементов стимулирует рост сеянцев в длину. Группы популяций, выделенные на основе морфологических признаков шишек (фенотипически), не поддаются определению по морфологическим особенностям сеянцев и по их минеральному составу.