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Phosphorus uptake by spruce (*Picea abies* (L.) Karst.) seedlings of various provenance

INTRODUCTION

Provenance studies on Norway Spruce have frequently demonstrated that within the range of the species there exists considerable genetic differentiation. As a result, from the economic point of view it has become very important to select the appropriate seed source before making collections for use in silviculture. So far the provenance experiments have yielded information about the genetic value of very few seed sources. It is not feasible to expect that ever will information be available for all forest regions. For this reason it would be most valuable if we could find correlations between characters of economic importance observable on mature trees and the physiological characters of seedlings. With this in mind a series of experiments was undertaken on spruce seedlings of various provenance cultured in the greenhouse under differentiated mineral nutrition. Results on the reaction of these seedlings to various nitrogen concentrations have already been published (Giertych and Fober 1967 a, 1967 b, Fober and Giertych 1968). Simultaneously a morphological analysis was made of the cones from which the seeds have been extracted for these experiments (Chylarecki and Giertych 1969) and using the same seeds a large field experiment was established on the provenance differentiation of Polish spruce (Giertych 1970). In the future it may be possible to seek correlations between the results obtained in the field and the early tests being conducted now. In the present paper we present further results of greenhouse experiments, namely those on the effect of various levels of phosphorus supplied in mineral solutions on the growth and development of spruce of various provenance.

In the literature there are not many data on the provenance differences in the uptake of phosphorus by forest trees. Mergen and Worrall (1965) have shown that phosphorus concentration in *Pinus banksiana* Lamb. seedlings of various provenance was higher for pines from the more northern and more western localities than from southern and eastern

ones. This concentration was correlated negatively with seedling dry weight.

In the studies on the phosphorus content in the needles of *Pinus silvestris* L. of various origin Steinbeck (1965) has found significant differences but without distinct geographic correlations, however of the five provenances studied the highest phosphorus concentration was found in the pines from the Urals that is from the most north-eastern locality and the lowest in the pines from Spain, that is from the most south-western locality. Since the climatic trend in Eurasia along the SW-NE axis corresponds to the NW-SE trend in North America, it can be assumed that Steinbeck's (1965) result is analogous to the one reported by Mergen and Worrall (1965) particularly so since, also in *Pinus silvestris*, three year old seedlings that have had the highest phosphorus concentrations (from the Urals) were also characterized by the lowest growth intensity (Wright and Bull 1963).

Kral (1961) has shown that spruce seedlings from high Alpine provenances have had higher phosphorus concentrations than seedlings from lower stands. Here also there was a negative correlation between the size of the seedlings and the phosphorus concentration.

In all the three papers referred to (Mergen and Worrall 1965, Steinbeck 1965, Kral 1961) their results were similar for nitrogen and phosphorus. In a study on seedlings of *Pseudotsuga menziesii* (Mirb.) Franco (Kral 1965) as well as in the one on older needles of *Pinus silvestris* L. (Gerhold 1959) significant provenance differences have not been found in the phosphorus concentration.

The studies of Ingestad (1959) on the effect of differential mineral nutrition on the growth and development of spruce seedlings have shown that a deficiency in phosphorus supply results in young needles being shorter and more yellow and the old ones being dark green, often with a violet tint. Terminal buds are sometimes formed and roots are long, thin and represent a greater proportion of the total seedling dry weight than is the case when they are grown on a full medium. Ingestad believes that optimal phosphorus concentrations in the dry weight should amount to 0.23% for needles and 0.41% for the roots. Symptoms of phosphorus deficiency are observable only at concentrations below 0.11% of needle dry weight. Spruce demonstrates considerable tolerance to variations in internal phosphorus concentrations of the needles between 0.12 and 0.30%.

MATERIALS AND METHODS

For the experiment use was made of small clay flower-pots with a capacity of about 150 cm³, covered within by a thin layer of paraffin, and filled with a 1 cm layer of gravel and yellow technical sand. So prepared

pots have been watered with distilled water for a period of two months in order to purify the sand.

Between the 4th and 14th of November 1966 into the pots partially germinated seeds of *Picea abies* (L.) Karst from 20 different provenances and representing various populations of spruce in Poland, have been planted (table 1, fig. 1).

Table 1
List of spruce provenances used in the experiment

Prov. no.	Locality	Lat.	Long.	Alt. m
1	2	3	4	5
S-04-101	Rycerka	49°32'	19°00'	530
S-03-100	Wisła	49°37'	18°56'	650
S-03-99	Istebna	49°33'	18°52'	630
S-04-103	Gorce	49°31'	20°07'	1000
S-16-96	Brody	51°42'	14°53'	80
S-01-119	Augustów	53°54'	23°11'	130
S-07-111	Nowe Ramuki	53°39'	20°34'	153
S-09-104	Wetlina	49°08'	22°30'	700
S-07-110	Hawa	53°39'	19°34'	116
S-14-109	Konstancjewo	53°11'	19°08'	90
S-10-107	Eliżyn	51°05'	20°42'	320
S-15-98	Kowary	50°48'	15°52'	625
S-05-122	Międzyrzec	52°03'	22°57'	154
S-01-121	Zwierzyniec	52°43'	23°47'	160
S-11-113	Myszyniec	53°22'	21°09'	120
S-15-125	Stronie Śląskie	50°18'	16°55'	870
S-01-117	Gołdap	54°20'	22°24'	150
S-01-118	Suwałki	53°59'	23°07'	170
S-01-120	Białowieża	52°40'	23°47'	160
S-04-133	Dolina Chochołowska	49°13'	19°48'	1400

Initially each pot contained 16 seedlings, and after 8 months the number of living ones was counted and they were all reduced to 5 plants per pot.

The second source of variation was the composition of the 4 mineral solutions used for feeding the cultures. These are designated in this paper as OP, 1/4P, 1/2P, 1P, and they differ in phosphorus concentrations, being respectively 0 mg/l, 2.5 mg/l, 5 mg/l and 10 mg/l. The remaining elements were supplied in the following concentrations: N — 48 mg/l, K — 49 mg/l, Ca — 40 mg/l, Mg — 15 mg/l, Fe — 19 mg/l, S — 32 mg/l, Na — 46 - 54 mg/l and a 1 ml/l of a solution with microelements. All 4 solutions have had a pH=5. The plants have been watered with the nutrient solutions twice weekly applying 10 ml per pot, and on the remaining week days with distilled water only.

The experiment was replicated thrice, thus the plants grew in 240

flower pots (20 provenances \times 4 levels of phosphorus \times 3 replicates) all randomized on the greenhouse sills.

During the fall and winter months the photoperiod in the greenhouse was extended to 16 hours with the help of a tungsten lamp controlled automatically.

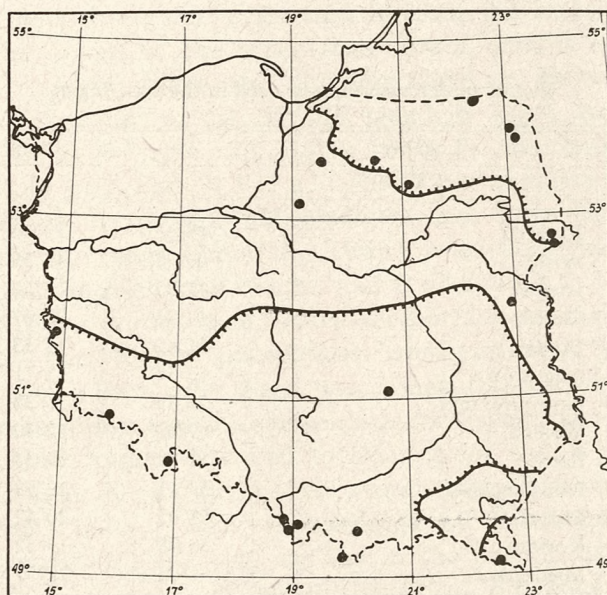


Fig. 1. Map of natural distribution of spruce in Poland and the location of stands where seeds have been collected

During the experiment observations were made on the growth and development of the seedlings. In August 1967 the needle colour was estimated with the help of the Horticultural Colour Chart (1938) and in September 1967 the height of the seedlings was recorded. Between the 27th of November and the 6th of December, that is after 13 months of plant growth the experiment was terminated and similarly as in the experiment described earlier (Fober and Giertych 1968) several measurements were made of growth and developmental characteristics of the seedlings as well as analyses were made of the internal content of phosphorus, total and as percentage of dry weight. The phosphorus concentration has been estimated by the modified method of Kuttner and Lichtenstein coupled with dry ashing (Fink 1963). Apart from the experimental replicates each sample was analysed twice, on two different days.

All the results from this experiment have been subjected to a statistical analysis and in the further part of this paper only significant results are being discussed.

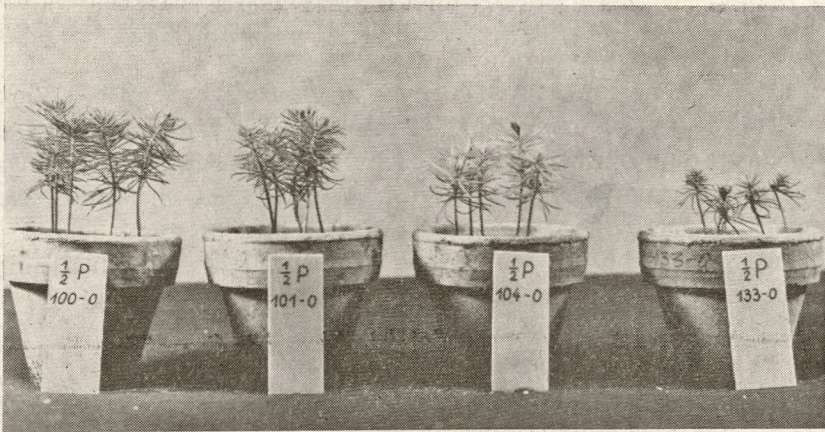
RESULTS

1. COLOUR OF SEEDLINGS

Significant differences in the colour of needles on the seedlings have been induced by the different levels of phosphorus supply. According to the accepted scale from the Horticultural Colour Chart, where the green colours range from bluish-green=53 to yellow-green=63, the seedlings have had the following average colours at the respective levels of phosphorus supply: OP — 57.3, 1/4P — 58.7, 1/2P — 58.0, 1P — 58.3, and the significant difference pertained only the seedlings grown on OP medium, which had a distinctly more bluish tint than the remaining ones. No significant differences have been observed between seedlings from various provenances.

2. SEEDLING HEIGHT

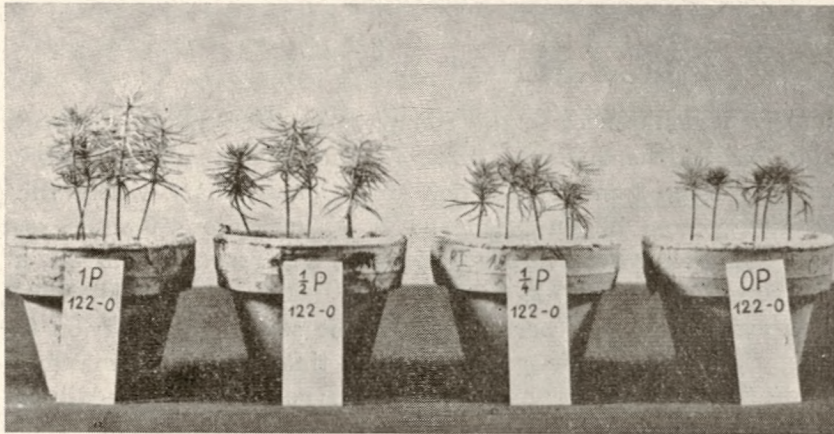
Throughout the duration of the experiment the seedlings grew relatively poorly. After four months of growth they have reached an average height of about 4 cm, however some of the montane provenances (Gorce, Dolina Chochołowska) had distinctly smaller seedlings than the remainder.



Fot. I. Kuberacka

Fig. 2. Spruce seedlings of four different provenances (Wisła, Rycerka, Wetlina, Dolina Chochołowska) growing on the 1/2P medium

The first measurement of the seedling height, from the level of the sand to the stem apex, has been made after 10 months of growth and two months after the number of seedlings per pot was reduced to 5. Average seedling height was at the time 5.2 cm and between provenances significant differences were observable (fig. 2). A considerable influence on the seedling height was exerted also by the level of phosphorus



Fot. I. Kuberacka

Fig. 3. Spruce seedlings of one provenance (Międzyrzec) growing on four different levels of phosphorus in the medium (1P, 1/2P, 1/4P, OP)

in the medium (fig. 3). At lower levels of phosphorus supply seedling height increased proportionately to the supply, however the maximal height was reached on the 1/2 P medium, that is at half the optimal concentration of phosphorus recommended for spruce (Ingestad 1959).

The second height measurement was made after 13 months of growth, that is at the time of experiment termination. This measurement is the more accurate one since it was made by placing each seedling on millimeter paper, straightening it out and recording the distance from the root collar to the stem apex. Results of this measurement do not differ significantly from those made earlier, and the slight individual differences result presumably from inaccuracies made in the first measurement.

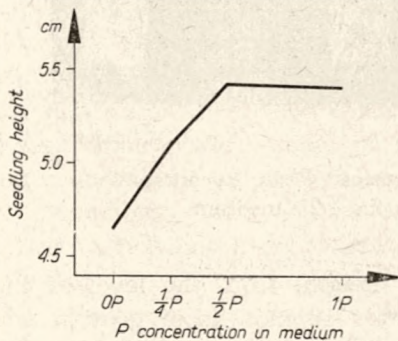


Fig. 4. Relation of seedling height to the concentration of phosphorus in the nutrient medium

The average height was also 5.2 cm. That is during the last 3 months of the experiment the seedlings did not grow in height. The provenance differentiation was maintained (table 2) and the dependence of the height

on the level of phosphorus in the medium remained unchanged in character (fig. 4).

The results of the height measurements averaged for each of the provenance are correlated for the two measurements and for the average heights observed earlier in the experiment on the influence of differential nitrogen nutrition (F o b e r and G i e r t y c h 1968).

3. SEEDLING MORTALITY

The seedlings were counted twice, after 8 months and after 13 months. After the first count a thinning was made and only five of the most healthy seedlings have been left per pot.

On the average the number of seedlings that have died in percentage values amounted for the different levels of phosphorus supply to: OP — 4.3%, 1/4P — 9.3%, 1/2P — 5.5% and 1P — 5.9% as recorded in the first count and: OP — 0.3%, 1/4P — 10.7%, 1/2P — 7.3% and 1P — 1.7% in the second. It is most noteworthy that both in the early and in the latter

Table 2

Seedling height and dry weight per seedling. Averages over all nutrient levels

Provenance	Seedling ht. cm	Dry weight mg			
		whole seedlings	needles	stems	roots
1	2	3	4	5	6
Rycerka	5.6	150.5	62.1	33.0	55.4
Wisła	5.4	129.5	52.4	29.9	47.2
Istebna	5.4	126.9	52.8	29.4	44.7
Gorce	5.0	122.4	50.5	29.1	42.8
Brody	5.3	121.9	48.8	28.7	44.4
Augustów	5.3	118.1	48.3	27.3	42.5
Nowe Ramuki	5.2	112.5	42.5	25.9	44.1
Wetlina	4.8	111.3	42.3	27.5	41.5
Ilawa	5.4	110.8	45.2	27.9	37.7
Konstancjewo	5.3	110.0	46.1	26.6	37.3
Bliżyn	5.3	106.7	43.1	26.6	37.0
Kowary	4.6	106.0	43.3	24.1	38.6
Międzyrzec	5.2	105.5	44.0	24.4	37.1
Zwierzyniec	5.3	103.1	38.9	26.0	38.2
Myszyniec	5.5	100.7	42.6	26.5	31.6
Stronie Śląskie	5.1	98.7	38.6	24.7	35.4
Gołdap	5.2	95.9	37.6	25.8	32.5
Suwałki	5.2	91.6	37.7	22.4	31.5
Białowieża	4.9	90.1	36.3	22.8	31.0
Dolina Choczołowska	4.1	77.8	28.5	20.0	29.3
Average	5.2	109.5	44.1	26.4	39.0

phase of the experiment the lowest mortality was at the OP level of phosphorus supply and highest at 1/4P level. No provenance differences have been recorded in this respect.

4. THE NUMBER OF SEEDLINGS WITH AN APICAL BUD

The percentage of seedlings with an apical bud was not differentiated significantly for the provenances nor for the levels of phosphorus supply, in spite of the fact that in the earlier experiment on the effect of various levels of nitrogen nutrition (Fober and Giertych 1968) this character was dependent both on the provenance and on the nutrition level.

5. NUMBER OF BUDS PER SEEDLING

The mean number of buds per seedling varied for the different provenances (table 3). On the average the greatest number of buds are to be found on seedlings from Rycerka. This provenance was also characterized by the greatest height, while at the other extreme the shortest seedlings, from Dolina Chochołowska, have had the least number of these buds. Also there is some interaction between the provenances and the level of phosphorus supply. In only very few provenances (Brody, Kowary, Międzyrzec) the number of buds per seedling increases with an increase of phosphorus supply. In the others the maximal number of buds develops at lower levels of phosphorus nutrition.

6. THE NUMBER AND LENGTH OF SIDE SHOOTS

The number of side shoots and their length depend on the origin of the seedlings (table 3) and on the level of phosphorus in the nutrient supply (table 5). Mean values of the number of shoots on a seedling are correlated with the results obtained earlier (Fober and Giertych 1968). The longest shoots are to be found on the seedlings from Kowary while those from Dolina Chochołowska were characterized by the shortest side shoots. There is no correlation between the seedling height and the number of side shoots on it. There exist therefore seedlings with a considerable height and relatively few side shoots, or in other words slender seedlings. Such is the case for the following provenances: Myszyńiec, Augustów, Zwierzyniec, Istebna and Bliżyn. The seedlings from provenance Kowary and Gorce are the least slender, they are short and have the largest number of side shoots. Similar differentiation can be demonstrated when comparing seedling height with the average length of the side shoots.

Table 3

Mean number of buds and the number and total length of laterals per seedling. Means over all nutrient levels

Provenance	No. of buds	No. of laterals	Total length of laterals (cm)
1	2	3	4
Rycerka	3.00	0.52	1.10
Wisła	2.37	0.42	0.83
Istebna	2.26	0.27	0.49
Gorce	2.90	0.45	0.82
Brody	2.48	0.43	0.80
Augustów	2.31	0.17	0.42
Nowe Ramuki	2.68	0.37	0.62
Wetlina	2.38	0.20	0.70
Ława	2.70	0.28	0.50
Konstancjewo	2.65	0.38	0.78
Bliżyn	2.28	0.20	0.47
Kowary	2.80	0.48	1.28
Międzyrzec	2.34	0.27	0.48
Zwierzyniec	2.39	0.18	0.32
Myszyniec	2.29	0.22	0.43
Stronie Śląskie	2.43	0.28	0.58
Gołdap	2.60	0.18	0.43
Suwałki	2.33	0.20	0.33
Białowieża	1.95	0.20	0.39
Dolina Choczołowska	1.75	0.10	0.21
Average	2.44	0.29	0.60

7. SEEDLING DRY WEIGHT

The mean dry weight of the seedlings is different for the various provenances (table 2) and for various levels of phosphorus in the medium (table 5). There exists also an interaction between level of nutrition and the provenances.

The sequence of the provenances in table 2 as well as that on all the other tables is in descending order of total dry weight.

The mean dry weight of a seedling varies between 77.8 mg (Dolina Choczołowska) and 150.5 mg (Rycerka). Thus the provenance differentiation is substantial considering that these are one year old seedlings. The average dry weight values correlate with those obtained earlier in the experiment on the effect of differential nitrogen nutrition (Fober and Giertych 1968). Very high dry weights have been obtained for provenances Wisła and Gorce which have not been studied in the first series.

The dry weight of seedlings of various provenances was not affected in the same fashion by the nutrient regimes employed. The provenances can be divided into three groups, in which all the seedlings have reached

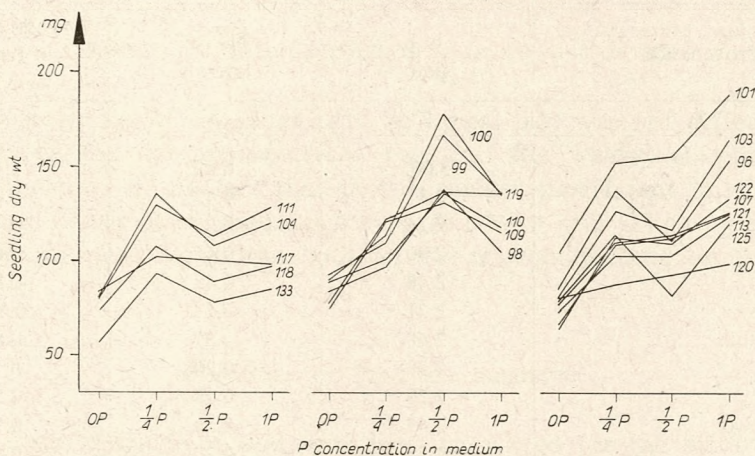


Fig. 5. Three types of relationships between the levels of phosphorus in the nutrient medium and the dry weight of seedlings of various provenances. Provenance numbers as in table 1

a maximum dry weight when grown on a medium with 1/4P, 1/2P or 1P level of phosphorus supply (fig. 5). The last group is the most numerous since it includes half of the studied provenances. There are in it provenances characterized by slow growing seedlings as well as those with seedlings of the greatest growth energy. The same concerns the second group, in which besides the slow growing seedlings from Konstanjewe and Hawa, also provenances Wisła and Istebna are to be found which on the average attain a very high total dry weight. The first group includes only provenances with slow growing seedlings such as Dolina Chochołowska, Suwałki and others.

8. THE DRY WEIGHT OF NEEDLES, SHOOTS AND ROOTS

Provenance differentiation in the dry weight of needles shoots, and roots (table 2) is correlated with the results obtained earlier in the experiment on the effect of nitrogen supply (Fober and Giertych 1968). Besides these values are highly correlated with the total dry weight. The extremal values belong to the same provenances, maximal to Rycerka and minimal to Dolina Chochołowska. In average over all the provenances an increase in phosphorus supply results in an increase in the dry weight of needles and shoots the maximum value being attained at the full 1P nutrition level. On the other hand the highest dry weight of roots was reached at the 1/4P level, the differences at the other nutrition regimes being slight (table 5).

9. RATIO OF ROOTS TO NEEDLES IN DRY WEIGHT

Mean values of this ratio decrease with an increase of phosphorus supply in the medium attaining lowest values on the 1/2P and 1P regimes (table 5). For individual provenances the lowest value of this ratio can also occur at the 1/4P level of phosphorus supply.

10. PHOSPHORUS CONTENT IN SPRUCE SEEDLINGS

The percentage (% of dry weight) and absolute (in mg per seedling) phosphorus content in the seedlings increases with an increase in phosphorus supply (table 5). This concerns the average values over all the provenances, and indeed for the majority of the provenances the seedlings attain highest levels of internal phosphorus content when grown on the 1P regime. However for a certain group of provenances maximal phosphorus uptake occurs on the 1/2P regime. This is true for provenances Istebna, Wisła, Konstancjewo, Iława and Augustów.

For individual provenances the mean percentage phosphorus content in the seedlings varies between 0.209 and 0.271% (table 4). These diffe-

Table 4

Phosphorus content in seedlings as percent of dry weight, in mg per seedling and ratio of absorbed phosphorus to root dry weight. Averages over all nutrient levels

Provenance	P content		mg P root dry wt.
	as % of dry wt.	mg per seedling	
1	2	3	4
Rycerka	0.270	0.426	0.769
Wisła	0.255	0.350	0.742
Istebna	0.234	0.321	0.718
Gorce	0.256	0.339	0.792
Brody	0.233	0.297	0.669
Augustów	0.264	0.329	0.774
Nowe Ramuki	0.271	0.317	0.719
Wetlina	0.259	0.308	0.742
Iława	0.209	0.243	0.645
Konstancjewo	0.221	0.255	0.684
Bliżyn	0.242	0.276	0.746
Kowary	0.231	0.259	0.671
Międzyrzec	0.235	0.278	0.749
Zwierzyniec	0.229	0.248	0.649
Myszyniec	0.218	0.235	0.744
Stronie Śląskie	0.239	0.245	0.692
Gołdap	0.256	0.248	0.763
Suwałki	0.256	0.245	0.778
Białowieża	0.217	0.196	0.632
Dolina Chochołowska	0.265	0.214	0.730
Average	0.243	0.281	0.720

Table 5

The influence of phosphorus concentration in the medium on the growth and other characters of spruce seedlings. Means per seedling over all the provenances

Character	P conc. in nutrient medium			
	OP	1/4 P	1/2 P	1 P
Total dry weight in mg	79.5	114.3	118.7	125.5
Dry weight of needles in mg	25.3	44.9	51.3	54.7
Dry weight of stems in mg	18.7	26.3	29.8	30.9
Dry weight of roots in mg	35.5	43.1	37.6	39.9
Ratio of roots to needles in dry weight	1.41	0.96	0.73	0.73
Number of buds	2.02	2.64	2.51	2.62
Number of laterals	0.16	0.31	0.27	0.43
Total length of laterals	0.24	0.64	0.58	0.93
Phosphorus % in dry weight	0.128	0.236	0.284	0.323
Phosphorus content in mg	0.102	0.275	0.339	0.409

rences are significant at the 0.10 level of confidence. The seedlings with the highest phosphorus concentrations come from Nowe Ramuki, Rycerka, Dolina Chochołowska and Augustów, that is both from the northern and southern parts of the species range in Poland. Seedlings from Ilawa have the lowest concentration of phosphorus i.e. 0.209% differing in this respect considerably from the remaining provenances.

Seedlings of provenances from the southern part of the species range in Poland are characterised by an internal phosphorus concentration that correlates with the elevation of the site of origin (fig. 6).

Significant differences are to be found also in the absolute phosphorus content per seedling for the various provenances (table 4). Provenances Rycerka, Wisła, Gorce, Augustów and Istebna have the highest phosphorus content per seedling and provenances Białowieża and Dolina Chochołowska the lowest.

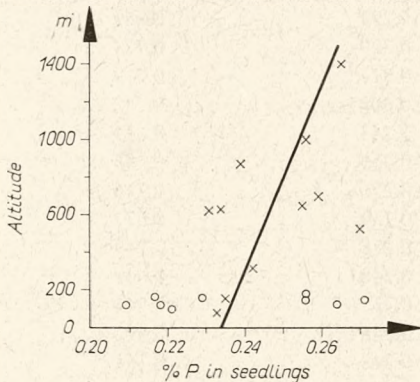


Fig. 6. Correlation of the phosphorus concentration in seedlings of spruce with the elevation of the site of seed origin (x — southern provenances, o — provenances from the lowlands of NE Poland)

No significant differences were found in the phosphorus content of the seeds of various provenances. It was on the average 1.04% (about 0.88 mg P per seed) of the dry weight.

11. RATIO OF THE PHOSPHORUS ABSORBED TO THE DRY WEIGHT OF ROOTS

Value of this ratio is a measure of the efficiency of the roots as phosphorus absorbing organs. In this respect seedlings with most efficient roots come from Gorce, Suwałki, Augustów, Rycerka and Goldap while at the other end of the scale provenances Białowieża, Ilawa and Zwierzyniec can be found (table 4).

DISCUSSION

In comparison with the results published earlier on the provenances differentiation as dependent on nitrogen nutrition (Fober and Giertych 1968) in the present experiment the seedlings grew rather poorly. On the average they have attained half as large a dry weight in spite of the fact that they grew for three months longer. This is true both for the means for the whole experiment as well as for the control seedlings grown on a full nutrient medium. Some conditions of the experiment have been altered, namely the flower pots have been lined on the inside with paraffin wax and the photoperiod has been extended in the winter to 16 hours by additional illumination with a low intensity light. It is very unlikely that either of these factors could have been responsible for the poorer growth. Extension of the photoperiod if it had any effect would tend to increase growth (Dormling et al. 1968). It may be that during the intervening year the seed has aged and lost some of its growth potential. However the most likely explanation is that climatic differences are responsible here. In 1966 the conditions were relatively uniform. On the thermohygrograph localized in the greenhouse there were no unusual fluctuations in the recorded temperature or humidity. During the summer of 1967 at a certain time the greenhouse was overheated, in spite of the fact that the window panes have been painted with chalk on the inside. On many of the seedlings sunscorching was observable at the time. This could have been the cause of the growth inhibition of all the seedlings until the end of the experiment.

In spite of the differences in overall size, most of the growth and morphological characters observed in the two experimental series were correlated with each other for the various provenances. Spruces from Wetlina and Białowieża are exceptions here. In the nitrogen series the seedlings from Białowieża and Zwierzyniec have shown considerable differences, in spite of the fact that they both originate from the same forest. In the present experiment the Białowieża provenance appears closer to Zwierzyniec, which should be considered as a more likely result. (In cone morphology no differences have been observed between these two populations, Chylarecki and Giertych 1969). The provenance from Wetlina in the present series appears in the group with the better

growing seedlings, whereas in the earlier experiment it was second last in growth.

Spruces from Wisła and from Gorce, which have not been included in the experiment on the effect of nitrogen nutrition, belong to the group of provenances with best growing seedlings, together with Rycerka and Istebna (table 2). This is very likely since the famous race of Istebna spruce has a much more extensive range than is often assumed.

The interaction between the provenances and the level of phosphorus supply with respect to dry weight was a complete surprise (fig. 5). It indicates that the levels of phosphorus supplied in the medium, though considered as optimal by Ingestad (1967) are not the most satisfactory for all races of spruce. Spruces of some of the provenances have attained maximal dry weight at a 1/2P or even 1/4P level of phosphorus supply, though this maximal value usually does not differ much from that attained on the 1P medium. However it must be pointed out that the provenances from the Silesian Beskids, that is Istebna and Wisła have attained a considerably higher dry weight at 1/2P than at 1P level of phosphorus nutrition. Coupled with the fact that these are provenances characterized by greater seedlings in average over the whole experiment (table 2) and that the roots of which are efficient phosphorus absorbing organs (table 4) this find has to be considered as important. It may constitute evidence for the existence of spruce races, highly productive on sites poor in phosphorus, and inhibited in growth when too high levels of this element are provided. This indicates that phosphorus fertilization can in certain situations be disadvantageous and that fertilization results observed on one race of spruce may not be employed in practice on other races without pilot trials.

The lower level of significance of the provenance differentiation on the basis of phosphorus concentration in the seedlings is in agreement with the results observed by other authors, which was mentioned in the introduction. This is presumably the result of lower accuracy of the analytical methods available for phosphorus than for nitrogen.

Even in the complete absence of phosphorus in the medium (OP) the concentration of this element in the seedlings was more than 0.11% (table 5). In needles only below this level deficiency symptoms are observable (Ingestad 1959). Our analyses have been performed on the whole seedlings. As we know from the studies of Ingestad (1959) roots have about twice as high phosphorus concentrations as leaves, and therefore in our material the concentration in the needles could have been much lower than 0.128% P, the value observed for the whole seedlings grown on the OP medium (table 5). Thus the fact that our seedlings cultivated on the OP medium did have deficiency symptoms (needle colour, poorer growth, high root/needle ratio etc.) does not imply disagreement with the results reported by Ingestad. The high per-

centage of phosphorus in the total dry weight does not also imply that the cultures have been contaminated with phosphorus from outside sources when grown on the OP medium, because the average phosphorus content was 0.102 mg per seedling (table 5), scarcely more than the 0.88 mg per seed.

The correlation of the phosphorus concentration in the seedlings with the elevation of the site of origin (fig. 6) was observed only for the spruces from the southern part of the range. Analogous result has been obtained when studying nitrogen concentration (Fober and Giertych 1968), with the difference that for phosphorus the correlation was weaker. Kral (1961) has obtained similar results for the Alpine spruce. In this respect characters linking the spruce from the Alps with that from southern Poland and differentiating them both from the spruce of northeastern Poland are manifest.

Provenance differentiation was observed for the efficiency of roots in phosphorus uptake similarly as was the case with nitrogen. However in contrast to the nitrogen results this character does not correlate with the total dry weight but is correlated with concentration of phosphorus in the seedlings. This implies that the more efficient are the roots in absorbing phosphorus the higher will be the concentration of the element in the seedlings. On the other hand no correlation is observed between the concentration of phosphorus in the spruce seedlings and their genotypic differentiation in growth characters. This has to be considered as the most important difference between phosphorus and nitrogen management in spruce seedlings. Better growing seedlings absorb more nitrogen as well as phosphorus but only the former is managed economically ($N\%$ is lower).

SUMMARY

Spruce seedlings of 20 Polish provenances have been cultivated in the greenhouse on 4 nutrient media differing in the concentration of phosphorus: OP, 1/4P, 1/2P and 1P. The highest concentration — 1P corresponds to the optimal value reported for spruce [10]. Symptoms of phosphorus deficiency have been observed only in seedlings cultivated on the OP medium, when the internal phosphorus concentration was 0.128% of the total seedling dry weight. Provenance differentiation with respect to most characters was correlated with the results obtained earlier on the uptake of nitrogen [4]. Spruces of various provenances have attained a maximum dry weight on various media. In particular the seedlings from Istebna and Wisła have grown distinctly better on a 1/2P medium than on 1P. Thus the requirements of spruces of various races for phosphorus are different, and a fertilization level that may be optimum for one race may prove inhibitive to another. Phosphorous con-

centrations in the whole seedlings differed for the provenances. Among those of the southern part of the range in Poland there was a correlation of that character with the elevation of the place of origin (similarly as was the case with N⁰/o). In contrast to N⁰/o however there was no negative correlation of P⁰/o with seedling dry weight.

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HENRYK FOBER i MACIEJ GIERTYCH

Przyswajanie fosforu przez siewki świerka różnych proveniencji

Streszczenie

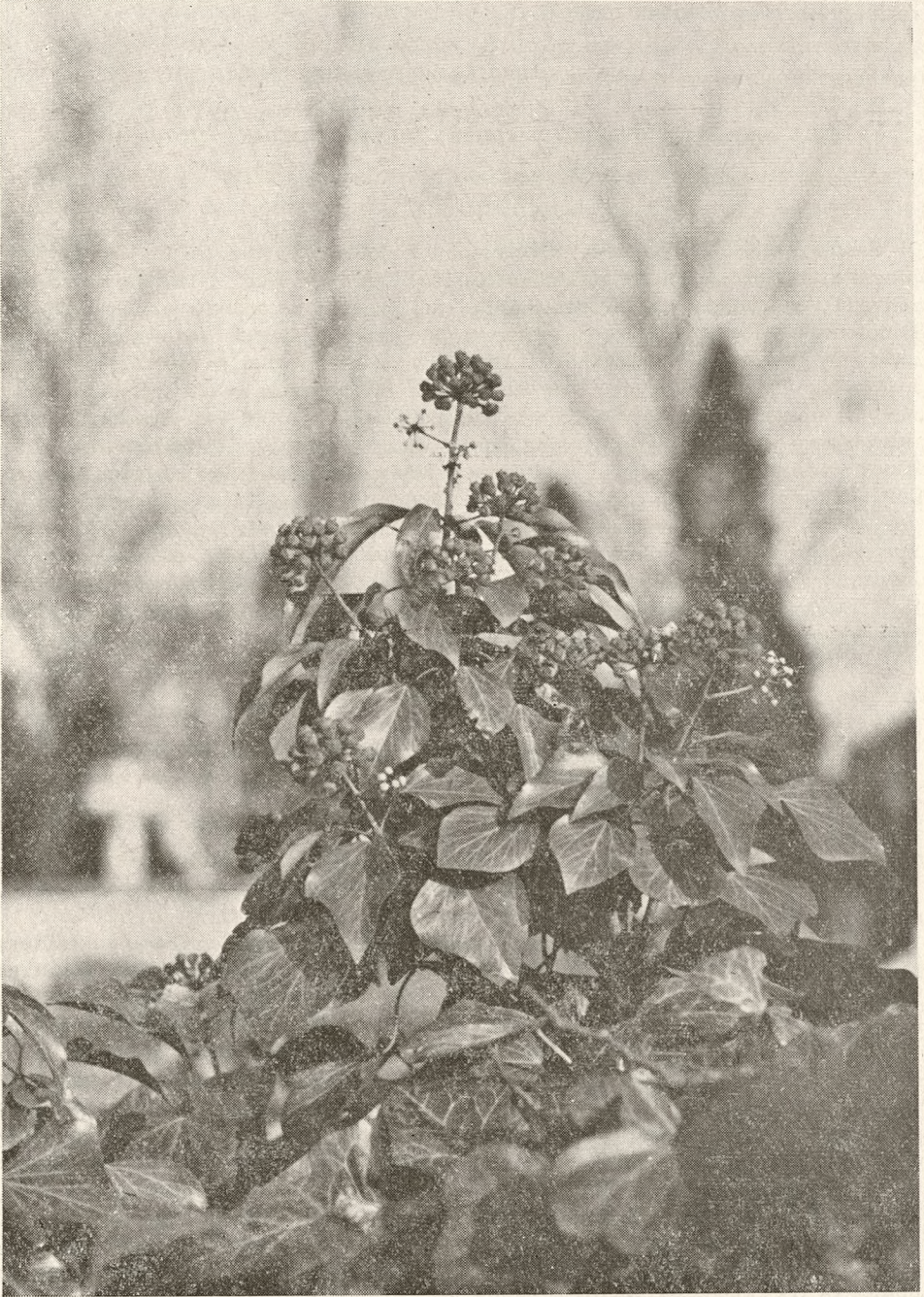
Siewki świerka 20 polskich proveniencji hodowano w szklarni na 4 pożywkach mineralnych, różniących się stężeniem fosforu: OP, 1/4P, 1/2P i 1P. Najwyższe stężenie, 1P, odpowiada wartości optymalnej dla świerka w oparciu o literaturę [10]. Symptomy niedostatku fosforu zaobserwowano tylko u siewek hodowanych na pożywce OP, posiadających średnio 0,128% P w ogólnej suchej masie. Zróżnicowanie proveniencyjne pod względem większości cech skorelowane było z wynikami otrzymanymi uprzednio w doświadczeniu nad pobieraniem azotu [4]. Świerki różnych proveniencji osiągnęły maksymalną suchą masę przy różnych poziomach fosforu w pożywce. Szczególnie siewki z Istebnej i Wisły wyraźnie lepiej rosły na pożywce 1/2P niż na pożywce 1P. Zapotrzebowanie świerka poszczególnych ras na fosfor jest więc różne, a poziom nawożenia optymalny dla jednej, może działać hamująco na inną. Stężenie fosforu w całych siewkach było różne dla różnych proveniencji. Dla proveniencji zasięgu południowego było ono skorelowane z wysokością nad poziomem morza terenu pochodzenia (podobnie jak %N). W odróżnieniu od %N nie było negatywnej korelacji między %P a suchą masą siewek.

ХЕНРЫК ФОБЕР И МАЦЕЈ ГЕРТЫХ

Усвоение фосфора сеянцами ели разного происхождения

Резюме

Сеянцы ели, происходящие из 20 разных районов Польши, выращивались в оранжерее на четырёх минеральных питательных средах, различающихся по содержанию фосфора: OP 1/4 P, 1/2 P, 1 P. Наивысшая концентрация (1 P) была, в соответствии с литературными данными [10], оптимальной для ели. Симптомы недостатка фосфора наблюдались только у сеянцев, культивировавшихся на среде OP, содержащей в среднем 0,128% фосфора в общей сухой массе. Различия между сеянцами разного происхождения по большинству признаков коррелировались с данными, полученными ранее в опытах по азотному питанию [4]. Ели разного происхождения достигали максимальной сухой массы при разных уровнях содержания фосфора в питательной среде. В частности, сеянцы из Истебной и из Вислы росли заметно лучше на среде 1/2 P по сравнению со средой 1 P. Следовательно, потребности разных рас ели в фосфоре различны, и оптимальная фаза удобрения для одной расы может тормозить рост сеянцев другой. Содержание фосфора в валовой массе сеянцев, различного происхождения было неодинаково. Для сеянцев, происходящих из южной части страны, оно коррелировалось с высотой над уровнем моря (аналогично содержанию азота). Однако, в отличие от азота не обнаружено отрицательной корреляции между процентом содержания фосфора и сухой массой растений.



Fot. K. Jakusz

Kwitnące i owocujące pędy bluszczu (*Hedera helix* L.)