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Early height growth of Scots pine (*Pinus sylvestris* L.) progenies from Polish clonal seed orchards

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Abstract: Seed orchards are expected to produce geneticaly improved seeds while maintaining a sufficiently large genetic diversity. Field trials comparing open-pollinated Scots pine progeny from seed orchards and commercial seed stands were established at five climaticaly different sites in Poland. The paper presents first height measurements obtained on trees at age 4. Seedlots differed significantly, but there was no strong evidence of better performance of clonal seed orchards progeny over the progeny of production seed stands. There was no distinct geographical trend in the origin of the best growing seedlots, but populations from the northern part of country tend to perform better than south-eastern ones. Progeny of the local production seed stands at their native environment were not the best, except in one case. A strong site effect reflecting a fertility gradient of the planting sites was found.

Additional key words: seed stand, progeny testing

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Introduction

Scots pine (*Pinus sylvestris* L.) is a very important tree species in a number of countries due to usefulness of its wood to many commercial uses. Within its extensive natural geographic range, the widest in genus *Pinus*, Scots pine exhibits considerable genetic variation. Diversity in desirable traits entailed first seed movements in Europe as early as in the 18th century (Daszkiewicz 2002). This was also the case for the first provenance experiments, established in France in the 19th century (Giertych 1993; Daszkiewicz 2002). Since that time the ecotypical or clinal variation within this species in a number of traits has been well known basing on results from many provenance tests (Wright and Bull 1963; Steinbeck 1966; Wright et al. 1966; Giertych 1979; Giertych and Oleksyn 1992; Stephan and Liesebach 1996; Shutyaev and Giertych 1997, 2000; Oleksyn et al. 1998, 2000, 2001, 2002; Chmura 2000 a,b). Polish provenances of Scots pine belong to the group of the best growing ones in most international experiments (Giertych 1979, 1980; Oleksyn et al. 1986), however also within the country a distinction between the best and less valuable populations is possible (Cierniewski and Przybylski 1978; Matras 1989; Giertych 1997; Sabor and Stachnik 1990; Rożkowski 1999).

To obtain more genetic gain stronger selection is needed. Comparison of families within provenances and individuals within families seems to be the most promising method of selection in Norway spruce (Giertych 1985, 1991). Progeny testing in forest trees is time- and cost-consuming. For these reasons the choice of plus trees basing on phenotypical traits precedes progeny testing. It is expected that their excellent performance is geneticaly determined and will be transfered to the progeny. For this purpose plus trees are grafted and clonal seed orchards are established. In Polish State Forests there are now 43 (385 ha) clonal seed orchards of Scots pine which should produce geneticaly improved seeds. Since in forestry practice open-pollinated seeds from those orchards are usually collected, the question raises whether such progeny is really better than that from production seed stands. There is some evidence that a better performance of progeny from seed orchards could be expected in Scots pine (Ackzell and Lindgren 1994; Hüller et al. 1995; Kohlstock et al. 1996) but this kind of comparison (seed orchards vs. production seed stands progeny) is still scarcely present in literature.

This paper presents the first results obtained on series of experiments comparing open-pollinated progeny from different seed orchards and from production seed stands in Poland.

Material and Methods

Plant material

At the time of planning the experiment in 1997 there were 42 Scots pine clonal seed orchards in Poland. Seeds were collected from 34 sites all those where grafts flowered and fructified. Each seedlot consists of a seed mixture from the whole orchard. Details regarding origin, number of clones and grafts at each orchard are presented in Table 1. Five progenies of commercial stands representing local populations for the 5 planting sites were also included as reference material (Table 1). In Polish forestry practice there is not common to move clones for seed orchards over large distances as was described for *Pinus sylvestris* L. in Sweden (Dormling and Johnsen 1992) or *Picea abies* (L.) Karst. in Norway (e.g. Johnsen 1989). Within the tested orchards only two represent non indigenous provenances. Sulechów 2 (17) is a seed orchard of "Tabórz pine" from north-eastern Poland and Brzeg (15) consists of Scots pines of unknown provenance from Germany.

Seeds were sown in spring 1998 at the commercial nursery in Jarocin (51°58' N 17°31' E). Seedlings were grown for the one season and were lifted as one-year-old (1/0). Each seedlot was planned to be represented at all locations but some of them (Table 1) had insufficient seedlings and then were replaced by a commercial seedlot local for the Jarocin nursery.

Experimental sites

In spring 1999 the five experimental areas were established. Each site was designed as having 195 plots in five completely randomised blocks (39 plots per block). Seedlots were randomly chosen for the plots in a block at each area independently. On each plot 100 seedlings were planted in 5 rows by 20 seedlings. Plots were assigned before planting and permanently marked with concrete poles with numbers in the corners.

Wymiarki Forest District, Gozdnica Forest Sub-District, Zabłocie Forest Range, Forest Compartment 243c (51° 22' 30''N 14° 59' 00''E, 155m a.s.l.; Fig. 1).

The experiment in Wymiarki was established on a plain clear-cut area after removing a Scots pine stand. The soil is a coarse sand of haplic podzol type. The soil was ploughed in the autumn, a year before planting. Seedlings were lifted from the nursery a day before planting, bound in bunches by 100 and transported to the experimental site. Then they were planted on the 16th and 17th of March 1999 at 1.5×0.5 m spacings. Additional boundary trees were also planted on the perimeter of the area. In the autumn of 1999 the area was fenced against game. This area contains all the 39 tested populations.

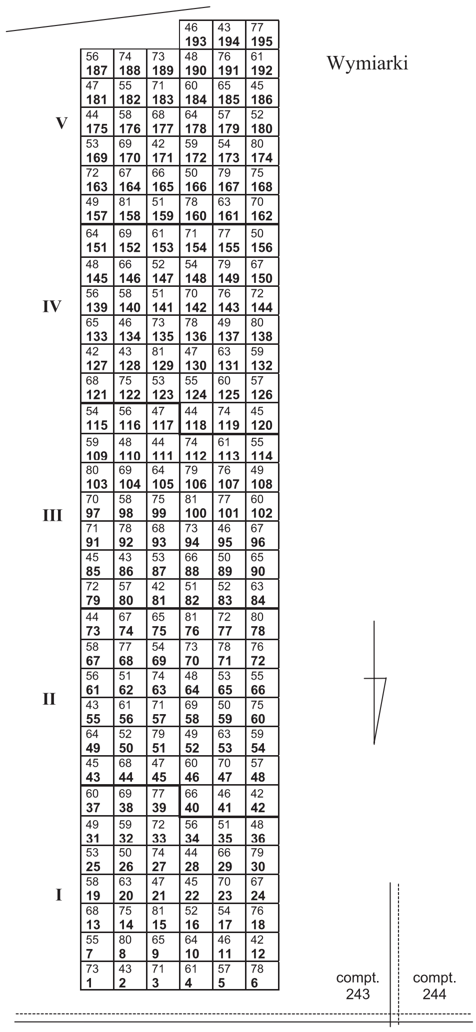

Fig. 1. Lay-out of the experimental site in Wymiarki. Bold fonts mean plot numbers, small fonts mean population numbers as referred to the last two digits of signature of each population in Table 1. Thicker lines show borders between blocks

Janów Lubelski Forest District, Władysławów Forest Sub-District, Zdzisławice Forest Range, Forest Compartment 54c (50° 37' 00''N 22° 36' 00''E, 210 m a.s.l.; Fig. 2).

Seedlings for planting in this site were lifted on the 22nd of March, their roots were gelled against drying and then they were transported to the planting area. The experiment is located on a plain clear-cut after removing a Scots pine stand. Soil is a coarse sand of haplic podzol type. The soil was ploughed in the autumn, a year before planting. Planting was conducted on the 24th and 26th of March at 1.5×0.5 m spacings. Directly before planting the seedlings were treated with a 1% solution of SHERPA 10 EC (Aventis CropScience, France) insecticide (10% cyphermethrin) against the pine weevil (*Hylobius abietis* L.). Population from Łomża had insufficient seedlings to plant on this area and the three subsequent ones.

Institute of Dendrology in Kórnik, Zwierzyniec Experimental Forest, Forest Compartment 1c, 2a (52° 14' 40''N 17° 03' 30''E, 80 m a.s.l.; Fig. 3).

The experiment was established on a former agricultural flat area. The soil is a sand or loamy sand of eutric cambisol type. The soil was ploughed in the autumn, a year before planting and harrowed in the spring. Seedlings were lifted on the 1st of April, roots were gelled against drying and then they were stored in an ice house (cold store cooled by natural ice) for a week. Seedlings were planted on the 6th to 8th of April at 1.5×0.5 m spacings. Additional boundary trees were also planted around the area. On this area populations from Ostrowiec Św. and Łuków had insufficient number of seedlings to plant on all plots. They are not present also on two subsequent areas.

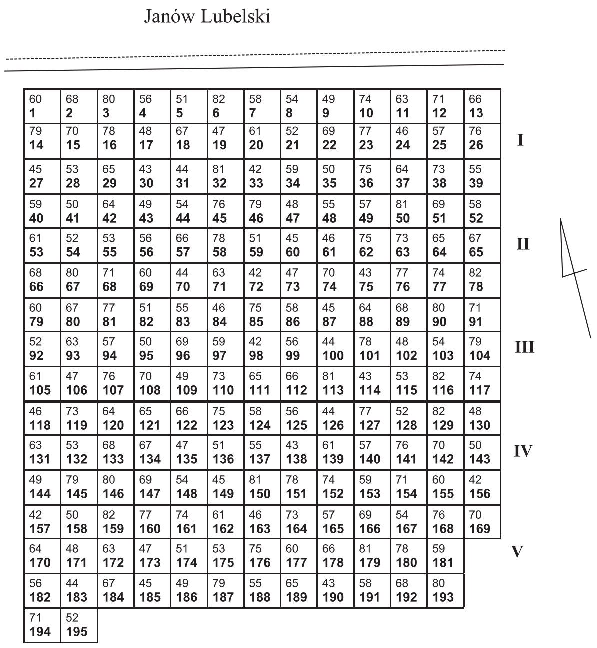

Fig. 2. Lay-out of the experimental site in Janów Lubelski. See explanation in Fig. 1

For the next two experimental sites seedlings were lifted from the nursery on the 7th of April, and then stored in the ice house until planting time. Roots were treated with gell against drying.

Choczewo Forest District, Młot Forest Sub-District, Dąbrówka Forest Range, Forest Compartment 154j (54° 39' 30''N 17° 58' 40''E, 120 m a.s.l.; Fig. 4).

The area was established on a former agricultural land with slight south-western exposure. The soil is of eutric cambisol type. The soil was ploughed in the autumn, a year before planting and harrowed in the spring. Seedlings were planted on the 14th and 15th of April at 1.4×0.5 m spacings. Boundary trees were also planted on the perimeter and the area was fenced against game. For weed control the area was treated with the Fusilade Super 125 EC (Zeneca Ltd., GB) herbicide (fluazifop-P-butyl).

Gołdap Forest District, Żytkiejmy Forest Sub-District, Błąkały Forest Range, Forest Compartment 345f (54° 18' 30''N 22° 40' 00''E, 220 m a.s.l.; Fig. 5).

The experimental area was located on hilly landscape formed from glacier deposits. The former stand was destroyed by wind. The area was cleared and soil was ploughed in the autumn a year before planting.

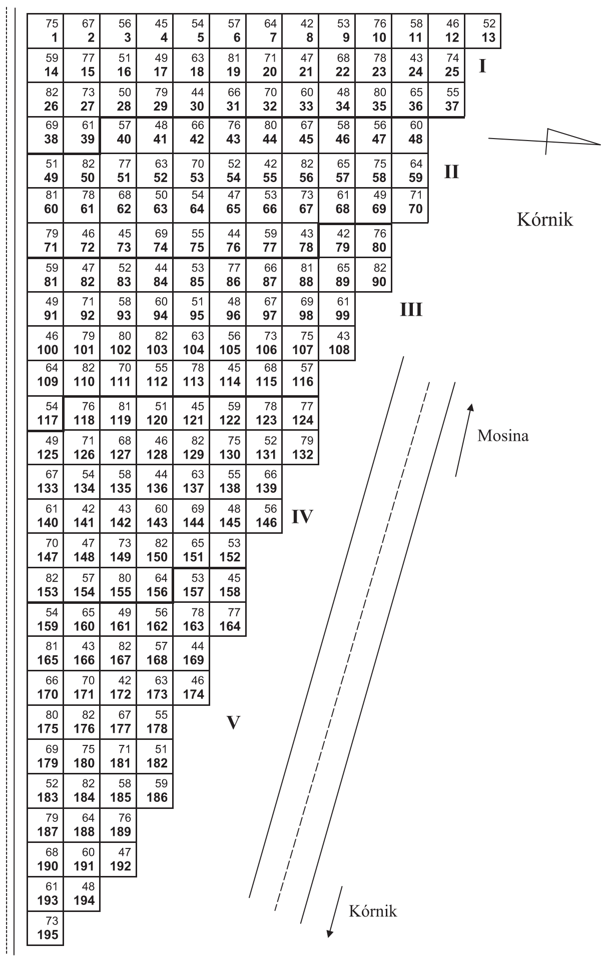

Fig. 3. Lay-out of the experimental site in Kórnik. See explanation in Fig. 1

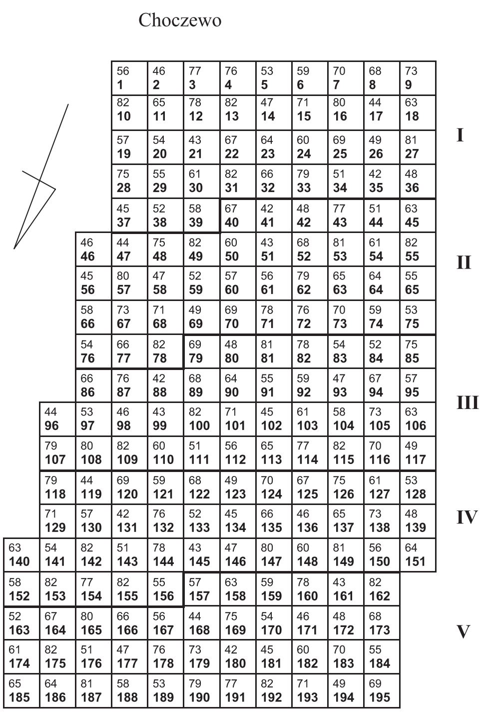

Fig. 4. Lay-out of the experimental site in Choczewo. See explanation in Fig. 1

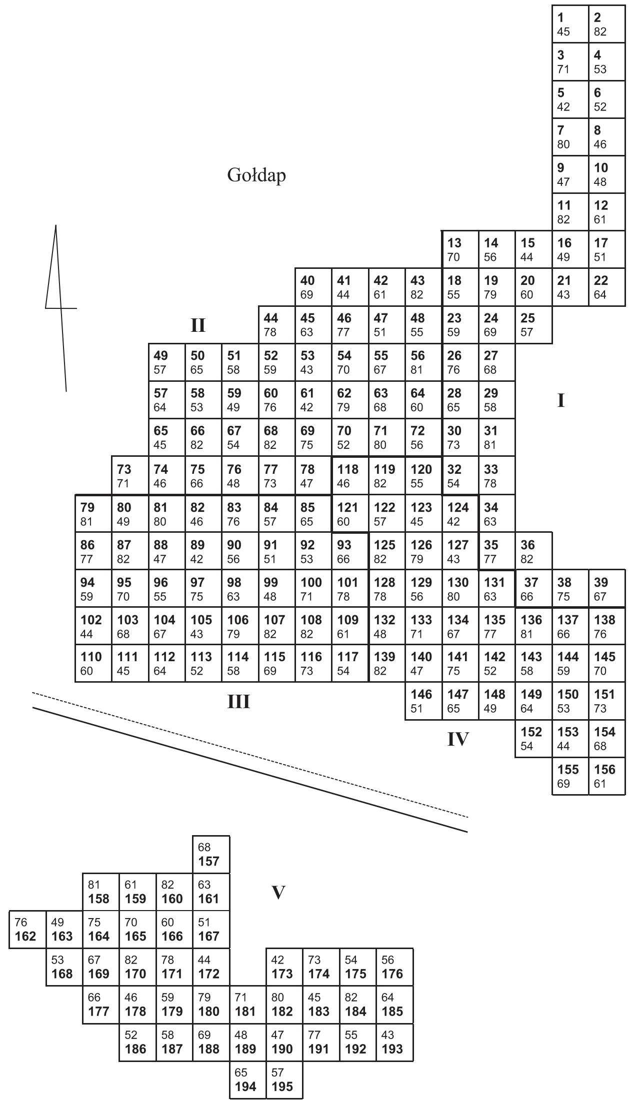

Fig. 5. Lay-out of the experimental site in Gołdap. See explanation in Fig. 1

The soil is sand or gravel of cambic arenosol type. Four blocks were clustered together and the fifth was located on the other side of a forest road. Seedlings were planted on the 20th and 21st of April at 1.5×0.5 m spacings. Additional boundary trees were also planted on the perimeter and the area was fenced.

Measurements

After three years of growing, in autumn 2001 (age 4 years), height of all trees at all locations of the experiment was measured. In the young age height is the best predictor of genetic value. To determine differences in height growth between populations analysis of variance was performed for each area independently using the model:

$$Y_{ijk} = \mu + a_i + b_j + ab_{ij} + e_{ijk} ,$$

where

Y_{ijk} is height of kth tree from ith population in jth block , μ is the overall mean, a_i is fixed effect of ith population, i = (1, ... , 37) or (1, ... , 39), b_j is random effect of jth block, j = (1, ... , 5), ab_{ij} is the interactive effect of populations with block and e_{ijk} is the residual. Number of analysed populations differed depending on available seedlots at each site.

Analysis for all experimental sites together was also done on the basis of mean height for each population in each block using the model:

$$Y_{ijkm} = \mu + l_i + a_j + la_{ij} + b_{k(i)} + e_{ijkm} ,$$

where

Y_{ijkm} is the individual observation, μ is the overall mean, l_i is random effect of ith location, i = (1, ... , 5), a_j is fixed effect of jth population, j = (1, ... , 36), la_{ij} is the interactive effect of populations×location, $b_{k(i)}$ is random effect of kth block within ith location and e_{ijkm} is the residual. Populations not present at all experimental sites were excluded from the overall analysis.

All analyses were done using REML (restricted maximum likelihood) method for random effects with JMP 4. statistcal package (SAS Institute Cary, NC).

Results

Populations were significantly different regarding tree height at three of the five locations (except Gołdap and Janów Lub.). Blocks at three sites also differed significantly (except for Janów Lub. and Kórnik). Significant interactive effects of populations with blocks at all sites were also found (Table 2). Presence of this interaction complicates the direct evaluation of genetic effect on tree growth. In the overall analysis there is a strong effect of experiment location as well as population and block within local-

Table 1. Details of seed orchards and seed stands of Scots pine included in the experiment and height of trees of each population as a mean from five planting sites

No.	Signature	Population (Forest District)	No. of clones	No. of grafts	Trees' height at age 4	Height group
1	01-3642	Supraśl (Podsupraśl)	30	2066	60.7	1
2	14-3643	Gniewkowo (Wielowieś)	39	2530	59.0	1
3	07-3644	Dwukoły (Krajewo)	39	3360	58.0	2
4	15-3645	Międzylesie (Stary Waliszów)	29	1730	56.0	3
5	08-3646	Gniezno (Dolina)	38	1557	58.4	2
6	06-3647	Skierniewice (Rylsk)	99	3640	57.0	2
7	07-3648	Orneta [form. Zapor.] (Giedyle)	173	9000	57.5	2
8	07-3649	Zaporowo (Rosiny)	89	2870	60.5	1
9	10-3650	Ostrowiec Świętokrzyski (Potoczek) *	38	6223	56.6	
10	14-3651	Runowo 1 (Samsieczno I)	160	6233	51.4	4
11	14-3652	Runowo 2 (Samsieczno II)	160	6233	54.3	3
12	14-3653	Runowo 3 (Wąwelno)	74	1160	55.2	3
13	14-3654	Runowo 4 (Dębiny)	61	790	56.5	3
14	05-3655	Józefów (Rybnica)	40	1260	52.7	4
15	03-3656	Brzeg (Prędocin)	32	1876	57.7	2
16	16-3657	Sulechów 1 (Klenica I)	72	2939	55.3	3
17	16-3658	Sulechów 2 (Klenica II)	56	1264	56.9	2
18	13-3659	Bierzwnik (Radachowo)	48	2316	54.9	3
19	07-3660	Susz (Bukownica)	170	9838	57.4	2
20	13-3661	Nowogard (Żabowo)	75	4460	56.9	2
21	04-3663	Miechów (Wymysłów)	41	936	51.7	4
22	02-3664	Kwidzyn 1 (Rusinowo)	99	4326	55.4	3
23	02-3665	Kwidzyn 2 (Otława)	45	1051	56.1	3
24	12-3666	Zdrojowa Góra (Wildek)	71	3257	59.5	1
25	05-3667	Świdnik (Stary Gaj)	36	2800	57.0	2
26	12-3668	Biała (Krukowo)	44	2445	60.9	1
27	15-3669	Oborniki Śl. (Prusice)	42	1200	55.7	3
28	28-3670	Chełm (Wołkowiany)	37	256	54.4	3
29	08-3671	Syców (Międzybórz)	67	4849	56.5	3
30	01-3672	Łomża (Kołaki) *	64	704	46.6	
31	09-3673	Sieniawa (Głażyna)	44	2136	56.1	3
32	05-3674	Łuków (Ławki) *	39	1506	53.7	
33	09-3675	Leżajsk (Marynin)	43	717	54.9	3
34	08-3676	ID PAN Kórnik (Odz. 1Ac)	67	897	56.2	3
35	02-3677	Choczewo (Lębork)[1]			59.0	1
36	01-3678	Gołdap (Suwałki)[1]			52.7	4
37	08-3679	Babki (Zwola)[1]			55.2	3
38	05-3680	Janów Lub.[1]			52.2	4
39	16-3681	Wymiarki[1]			61.5	1
40	08-3682	Jarocin (Nowe Miasto)[1]* GDN, oddz.287g			63.5	
	mean				56.4	

* populations excluded from overall analysis; [1] – progeny of commercial seed stands; means for groups: 1 – 60.1; 2 – 57.4; 3 – 55.5; 4 – 52.1

Table 2. Analysis of variance results (F values and p values below) for each planting site

	Wymiarki	Janów Lub.	Kórnik	Choczewo	Gołdap
d.f.	38/4/152/13151	38/4/152/14813	36/4/144/16466	36/4/144/12706	36/4/144/11903
populations	1.82	1.18	4.44	4.31	1.48
	0.0060	0.2425	< 0.0001	< 0.0001	0.0569
blocks	44.34	0.80	1.71	3.13	9.87
	< 0.0001	0.5245	0.1501	0.0167	< 0.0001
populations × blocks	4.86	8.23	5.85	3.94	6.39
	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

d.f. – degrees of freedom for populations / blocks / interaction / error.

Table 3. Analysis of variance results for all plating sites

source	d.f.	F	p
locations	4	105.72	< 0.0001
populations	35	3.14	< 0.0001
populations × locations	140	0.80	0.9455
block (location)	20	9.95	< 0.0001
error	700		

isation effects. No interaction of population with planting site was found (Table 3). The tallest trees were in Kórnik (mean 74.5 cm), then in Choczewo (61.8 cm), Janów Lub. (50.0 cm), Wymiarki (48.5 cm) and in Gołdap (42.1 cm).

Populations were clustered using Ward's method basing on average tree height values for each seedlot at the five planting sites. Four significantly different (=0.05) groups of populations were distinguished. Mean height for each seedlot and its assignment to a group are presented in Table 1. There is no geographical trend in distribution of this trait in the tested progenies. Also a comparison between progeny of seed orchards and the commercial seed stands has not revealed any differences (p = 0.5747) in height growth. In the group of the best growers both seed orchard and seed stand progenies fall. This is also true for the group of the poorest growing ones.

Tree heights were ranked for each seedlot at all planting sites (Table 4). It is worthwhile to mention that the local commercial seed stands progenies were not the best growers at plantig sites except for Wymiarki. The overall rank for the 5 local populations at their sites is 14.8 [(1+8+10+22+33)/5] which is not far from the mean (18). Coefficient of variation (V) of ranks ranged from 12.2 to 156.6 %. The most stable is progeny of the Sulechów 2 (17) seed orchard, which is always in the middle of the rank. The most variable is progeny of the Supraśl (1) seed orchard, which is the best almost everywhere except Wymiarki where it is in the lower part of the rank.

Discussion

Seed orchards represent selected plus trees from registered seed stands and it is hoped that the good phenotype has a reflection in a good genotype. Basing on this assumption and to save money and time, establishment of seed orchards often precedes progeny testing, as was mentioned above. There is however some risk involved in such approach if those presumptions do not prove true.

In this experiment tested seedlots of Scots pine differed significantly, but suprisingly, there was no strong evidence of better performance of the clonal seed orchards progenies over the progeny of commercial seed stands. This implies that choice of a seed stand has crucial meaning in selection of forest trees. However, it was found that progenies of local stands are not necessarily the best growers at the planting sites except one. Similar results were obtained by Ackzell and Lindgren (1994). The Gołdap (36) seedlot was among the worst even in the local experiment. The effect of origin of clones on the progeny can be seen well on the example of the progeny from the Miechów seed orchard, which represent "Podhale pine" provenance from the Carpatian foothills. In our experiment it is a quite stably poor growing seedlot. Other provenance experiments showed also weak growth capacity of Scots pine from this region (Giertych 1997) even on a montane site (Sabor and Stachnik 1990), though it seems to improve its performance with aging (Sabor and Orzeł 1994).

Considering each planting site separately the differences between populations are not so obvious in all cases. Stronger differences between blocks have weakened the differences between genetic entries and interaction at all sites imply that observed differences can be to some extent determined environmentaly. The significant location effect on tree height in the overall analysis reflects a fertility gradient between experimental sites. Kórnik and Choczewo are the most fertile sites because they are located on formerly agricultural land. Although there is no geographical trend in the origin of the best growing seedlots, populations from the northern part of country tend to perform better, especially than south-eastern ones (see height group 1 in Table 1).

It is not the practice in Poland to move ramets to more favourable conditions to increase seed production. Most seed orchards included in the experiment

Table 4. Rank position of each seedlot at each planting site

No.	Population	Wymiarki	Choczewo	Kórnik	Janów Lub.	Gołdap	mean	V [%]
1	Supraśl	27	1	1	6	1	7.2	156.6
2	Gniewkowo	14	3	3	10	14	8.8	63.0
3	Dwukoły	11	16	8	9	13	11.4	28.2
4	Międzylesie	17	11	26	26	29	21.8	34.5
5	Gniezno	5	5	22	24	9	13	71.5
6	Skierniewice	4	32	20	7	18	16.2	69.1
7	Orneta	13	9	23	13	28	17.2	46.2
8	Zaporowo	6	2	6	8	6	5.6	39.1
10	Runowo 1	32	34	35	21	35	31.4	18.9
11	Runowo 2	15	14	31	29	7	19.2	53.9
12	Runowo 3	30	21	14	35	26	25.2	32.2
13	Runowo 4	21	23	15	11	32	20.4	39.5
14	Józefów	29	33	33	16	23	26.8	27.2
15	Brzeg	18	13	12	19	16	15.6	19.5
16	Sulechów 1	25	24	19	34	36	27.6	26.0
17	Sulechów 2	22	18	24	23	19	21.2	12.2
18	Bierzwnik	35	22	29	20	8	22.8	44.7
19	Susz	20	12	16	25	5	15.6	48.9
20	Nowogard	24	10	13	2	12	12.2	64.6
21	Miechów	34	36	34	27	15	29.2	29.6
22	Kwidzyn 1	16	26	27	15	25	21.8	26.6
23	Kwidzyn 2	26	15	21	32	10	20.8	41.8
24	Zdrojowa Góra	2	7	11	4	11	7	58.0
25	Świdnik	31	29	7	3	20	18	70.3
26	Biała	8	6	4	5	30	10.6	103.3
27	Oborniki Śl.	9	20	9	31	31	20	55.0
28	Chełm	33	31	18	30	22	26.8	24.1
29	Syców	3	17	30	28	27	21	53.6
31	Sieniawa	12	28	17	17	21	19	31.4
33	Leżajsk	7	30	25	12	4	15.6	72.9
34	IDPAN	23	4	28	14	3	14.4	77.4
35	Choczewo	10	8*	5	18	17	11.6	49.0
36	Gołdap	28	25	36	36	33*	31.6	15.6
37	Babki	19	27	10*	33	24	22.6	38.4
38	Janów Lub.	36	35	32	22*	2	25.4	55.9
39	Wymiarki	1*	19	2	1	34	11.4	129.6

* progeny of commercial seed stand local to the planting site.

were not moved far and represent valuable provenances near their site. Thus there is a rather low risk of environmental after-effects of the parental seed orchard which has been reported from Scandinavia (Dormling and Johnsen 1992; Lindgren and Wei 1994). There is always a question of the required number of clones in a seed orchard to ascertain a high level of genetic diversity. Many authors have recommended different numbers of clones but more than 20 – 30 seems to be the efficient amount (Giertych 1975; Skrøppa 1994). Almost all tested seed orchards consist of more than 30 clones, so genetic diversity should be maintained in their progeny.

First results obtained in this trial give some hope to find the best growing populations, but so far do not confirm the better growth of highly selected progenies. In afforestation effort rapid growth in the early years is very important. Trees from the Supraśl seed orchard are the highest at the northern locations and trees from the Wymiarki seed stand are the highest at the southern locations. This implies that the examined populations of Scots pine are not very plastic. Further investigations are needed however to find possible changes with age in this experiment.

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