JOURNAL OF FOREST SCIENCE, *50*, 2004 (12): 559–565

Adaptation of larch (*Larix decidua*) of Polish provenances under mountainous conditions of Beskid Sądecki (southern Poland)

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ABSTRACT: A long-term study carried out within the 1967 All-Poland Larch Provenance Experiment investigated genetic variation in 20 Polish provenances of larch growing under the site conditions of the Beskid Sądecki Mts. (at a test site in Krynica). The study was based on the measurements of tree height made in individual larch populations during 1969–1999, i.e. when trees were 5, 8, 11, 15, 20, 25, 30 and 35 years old. The results showed a considerable adaptation stability of the provenances tested at the Krynica site. This stability, however, tended to decrease with increasing mean height of trees. An estimation of the effect of the "genotype (provenance) × years of observation (age)" interaction revealed a high stability of height growth in larch populations having extreme values of this trait. As follows from the study, it is possible, especially in the case of the latter group of provenances, to carry out effective selection in the early stage of tree growth, thus ensuring a permanent genetic gain.

Keywords: European larch; provenance; genotype; planting experiment; Beskid Sądecki Mts.; Poland

Larch in Poland is scattered throughout the country and forms isolated islands (BAŁUT 1967; BORATYŃSKI 1986). Larger areas covered by larch occur only in mountainous areas such as the Saint-Cross Mts., Carpathians and Sudetes. Due to this scattered occurrence, two subspecies have been distinguished within the species *Larix decidua* (Mill.) in Poland: European larch (*Larix decidua* subsp. *decidua*) and Polish larch (*Larix decidua* subsp. *polonica* Domin.). Both subspecies include populations that differ not only in growth dynamics and productivity but also in many other characteristics (GIERTYCH 1979, 1980; KULEJ 1983, 1985, 1989, 2001; SCHOBER 1985; ŠINDELÁŘ 1992; WEISGERBER, ŠINDELÁŘ 1992; ANDRZEJCZYK, BELLON 1999).

One of the main objectives of modern silviculture is to extend knowledge of the genetic value of larch as a fast-growing pioneering tree species whose role in forestry should be increased. The All-Poland Larch Provenance Experiment, initiated in 1967, has contributed greatly to the achievement of this goal. Investigations carried out at the Experimental Forest Station in Krynica are a part of this experiment.

The present study aimed to estimate the adaptation traits and the effect of the interaction "genotype (provenance) × years of observation (age)", $G \times E_{age}$, in the Polish provenances of larch under the site conditions of the Beskid Sądecki Mts.

MATERIAL AND METHODS

A total of 20 larch provenances from the whole area of Poland were tested on an experimental site of the Experimental Forest Station in Krynica (Table 1, Fig. 1). Trees of each provenance were planted in five replications according to the Latin rectangle design. The detailed data on the maternal stands and parent trees of larch populations were published in an earlier work (KULEJ 2001).

The test site is located at an altitude of 785 m (i.e. in the middle part of the lower mountainous zone) in the Wojkowa Forest Range, in the Province of the Gorce and Beskid Sądecki Mts. of the VIII Carpathian Natural Forest Region.

The investigations were based on tree measurements carried out in individual larch populations during 1969–1999, i.e. when trees were 5, 8, 11, 15, 20, 25, 30 and 35 years old.

The adaptation traits of larch provenances were assessed using Finlay-Wilkinson's (1963) method and assuming the effect of the "provenance × locality × years" interaction as an adaptation index. Such an index provides a forest manager with the information about the stability range of a given population and the type of its response to changing environmental conditions (Fig. 2).

The assessment of the adaptation traits was based on the effect of the "provenance × years" interaction for one of the basic growth characteristics, i.e. the mean height of

Table 1. Location of maternal stands of larches investigated at a test site in Krynica within 1967 All-Poland Larch Provenance Experiment; numbering of provenances according to KOCIĘCKI (1977)

Prov. No.	Provenance name	Geographical coordinates		Altitude (m)	Natural forest region	Natural forest province
		latitude	longitude			
1	Myślibórz Północ	52°54′	14°52′	50–75	I – Bałtycka	Niziny Szczecińskiej
2	Pelplin	53°56′	18°43′	50–75	I – Bałtycka	Pojezierza Drawsko-Kaszubskiego
4	Konstancjewo "Płonne" reserve	53°07′	19°04′	50–75	III – Wielkopolsko-Pomorska	Pojezierza Chełmińsko-Dobrzyńskiego
6	Konstancjewo "Tomkowo" reserve	53°07′	19°04′	50–75	III – Wielkopolsko-Pomorska	Pojezierza Chełmińsko-Dobrzyńskiego
7	Czerniejewo	52°26′	17°30′	100–120	III – Wielkopolsko-Pomorska	Niziny Wielkopolsko-Kujawskiej
8	Rawa Mazowiecka	51°48′	20°15′	180	IV – Mazowiecko-Podlaska	Równiny Warszawsko-Kutnowskiej
9	Grójec	51°52′	20°52′	180	IV – Mazowiecko-Podlaska	Równiny Warszawsko-Kutnowskiej
10	Marcule	51°08′	21°15′	200–220	VI – Małopolska	Radomsko-Iłżecka
11	Skarżysko	51°10′	20°46′	350–400	VI – Małopolska	Gór Świętokrzyskich
12	Bliżyn	51°05′	20°45′	280–320	VI – Małopolska	Gór Świętokrzyskich
13	Świętokrzyski PN	50°55′	21°04′	300–400	VI – Małopolska	Gór Świętokrzyskich
14	Moskorzew	50°39′	19°56′	250	VI – Małopolska	Wyżyny Środkowomałopolskiej
16	Hołubla	49°48′	22°48′	300–350	VIII – Karpacka	Pogórza Karpackiego
18	Krościenko	49°27′	20°26′	640–660	VIII – Karpacka	Gorców i Beskidu Sądeckiego
19	Pilica	50°28′	19°40′	450	VI – Małopolska	Wyżyny Krakowsko-Częstochowskiej
20	Prószków	50°35′	17°52′	180	V – Śląska	Równiny Opolskiej
21	Henryków	50°41′	17°01′	300–350	V – Śląska	Przedgórza Sudeckiego i Płaskowyżu Głubczyckiego
22	Kłodzko	50°22′	16°45′	300–450	VII – Sudecka	Sudetów Środkowych
23	Szczytna Śląska	50°25′	16°26′	500–550	VII – Sudecka	Sudetów Środkowych
24	Kowary	50°48′	15°50′	500–550	VII – Sudecka	Sudetów Zachodnich

trees aged 35 from a given provenance. For trees of each provenance the coefficients of linear regression ($H_{prov} \times H_{loc}$) were calculated to show the range of the influence of environmental factors on the effect of the "provenance × years" interaction and on the magnitude of this effect and the changes caused by seasonal factors. When the regression coefficient b is equal to 1, a provenance has an average stability in a given environment, when $b > 1$ or $b < 1$, this stability is lower or higher than the average, and the effect of the "genotype × years" interaction is high in respect of tree height. A population with $b > 1$ exhibits a great reactivity to the environment (worsening or improvement in a given trait), while that with $b < 1$ shows a great stability. In genetic selection, a provenance is considered to be useful when the coefficient b is smaller than 1, since man has practically no influence on the improvement in the forest environment.

The effect of the interaction "genotype (provenance) × years of observation (age)" ($G \times E_{age}$) for tree height was analysed on the basis of changes in the ranking position of larch provenances and on their reactivity. The assessment was made according to the GALLAIS (1990) classification (as used by SABOR 1998): 1 – positive interaction, 2 – negative interaction, 3 – change in rank, 4 – no age effect.

RESULTS

Table 2 shows the data concerning the adaptation traits of larch assessed on the basis of the mean height of trees of individual provenances for successive study periods and the regression coefficients (b) describing stability. During the 1969–1999, the mean height of trees aged 5 to 35 years, expressed in percent of the experimental annual mean, ranged from 83 to 111%. The values for the Kłodzko and Prószków provenances in the Sudetes (> 100%) were considerably higher than the annual mean. Provenances from the Saint-Cross National Park

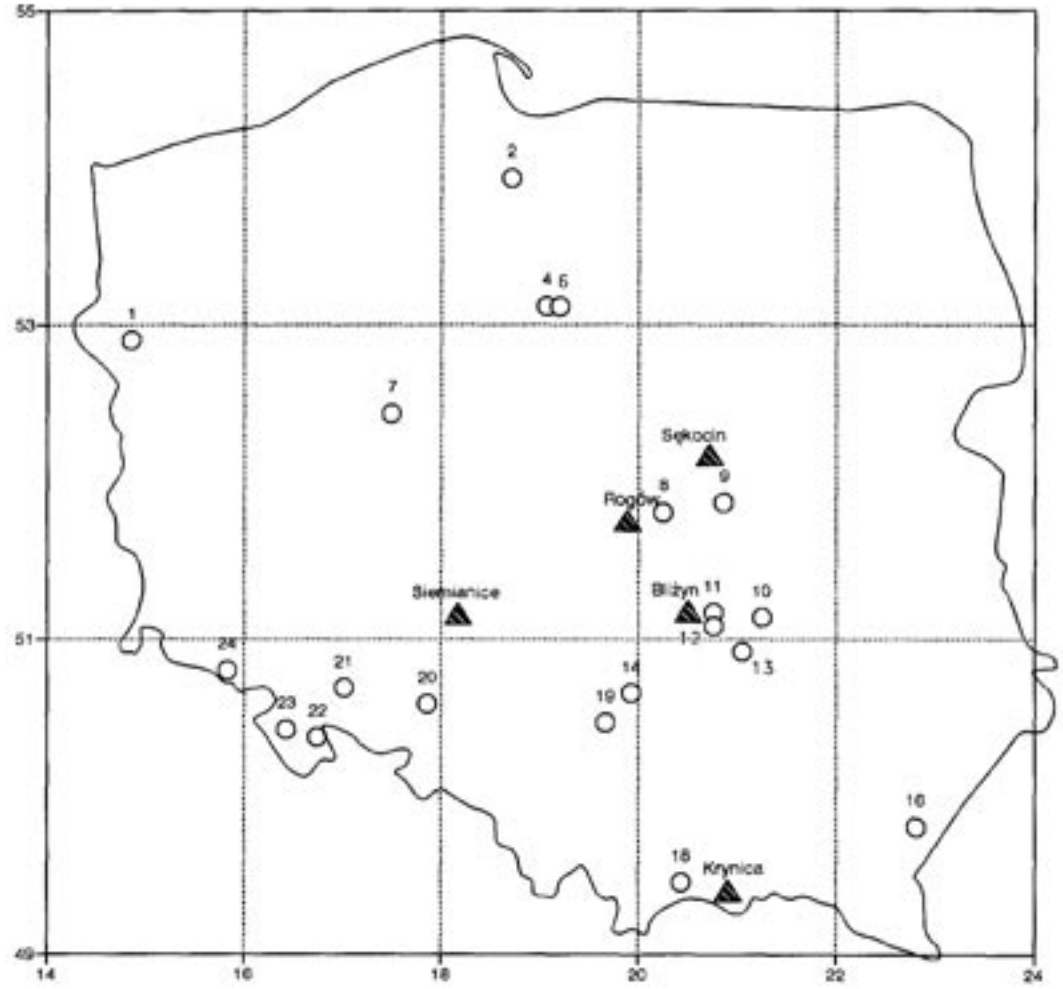

Fig. 1. Location of maternal stands of larches investigated within 1967 All-Poland Larch Provenance Experiment; ○ – provenance, ▲ – test site, 1–24 – provenance number: 1 – Myślibórz Północ, 2 – Pelplin, 4 – Konstancjewo – "Płonne", 6 – Konstancjewo – "Tomkowo", 7 – Czerniejewo, 8 – Rawa Mazowiecka, 9 – Grójec, 10 – Marcule, 11 – Skarżysko, 12 – Bliżyn, 13 – Świętokrzyski Park Narodowy, 14 – Moskorzew, 16 – Hołubla, 18 – Krościenko, 19 – Pilica, 20 – Prószków, 21 – Henryków, 22 – Kłodzko, 23 – Szczytna Śląska, 24 – Kowary

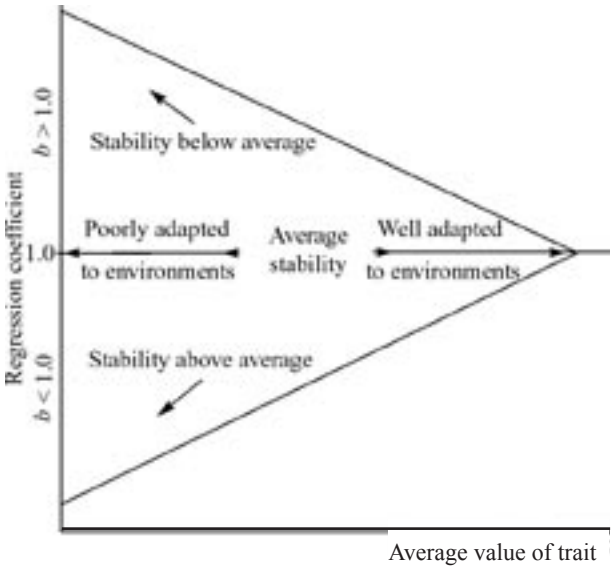

Fig. 2. Interpretation of stability and adaptation of larch provenances based on regression coefficients (*b*) and values of traits (FINLAY-WILKINSON 1963; SABOR 1993)

(Świętokrzyski PN), Moskorzew, Hołubla, Szczytna Śląska and Kowary may also be included in this group. Much lower values (< 100%) were obtained for larches from Rawa Mazowiecka, Grójec and Marcule.

An average adaptation stability ($b \approx 1$) in respect of tree height was observed in larches from Pelplin, Czerniejewo, Skarżysko, Bliżyn, Świętokrzyski PN, Moskorzew, Hołubla, Henryków, Kłodzko and Kowary. Provenances from the northern part of the country (Myślibórz Północ, Konstancjewo – "Płonne" reserve) and from the Sudetes (Prószków, Szczytna Śląska) showed a high reactivity to the changing site ($b > 1$). Such populations as Konstancjewo – "Tomkowo" reserve from northern Poland, Rawa Mazowiecka and Grójec from Central Poland, as well as populations from Krościenko, Pilica and Marcule proved to be very stable ($b < 1$).

The results of the assessment of the adaptation traits of larch provenances tested in Krynica, made on the basis of the adaptation index (*b*) and the mean height of trees (*H*) at the age of 35, are shown in Fig. 3. Based on the rela-

Table 2. Assessment of adaptation traits of larches using FINLAY-WILKINSON (1963) method – mean height of provenances in % of annual means; H_{1999} – mean height at age 35, b – regression coefficient

Prov. No.	Provenance name	Years								H_{1999} (m)	b
		1969	1972	1975	1979	1984	1989	1994	1999		
1	Mylibórz Północ	92	99	103	104	100	103	104	106	18.57	1.056
2	Pelplin	60	91	93	97	97	100	100	100	17.56	1.016
4	Konstancjewo – "Plonne"	97	96	94	102	100	104	106	101	17.66	1.043
6	Konstancjewo – "Tomkowo"	96	96	96	96	103	103	97	95	16.64	0.980
7	Czerniejewo	99	95	96	98	105	103	99	102	17.86	1.024
8	Rawa Mazowiecka	97	93	94	96	95	95	95	95	16.64	0.954
9	Grójec	97	97	94	94	93	91	94	92	16.17	0.920
10	Marcule	96	85	83	85	94	84	87	88	15.43	0.877
11	Skarżysko	107	103	102	103	99	104	101	100	17.49	1.004
12	Bliżyn	98	96	96	97	97	101	99	99	17.36	0.998
13	Świętokrzyski PN	105	105	105	102	102	101	100	102	17.84	1.005
14	Moskorzew	103	104	104	101	104	103	102	102	17.80	1.017
16	Holubla	102	105	103	100	104	96	101	101	17.73	1.000
18	Krościenko	95	104	100	100	98	97	98	94	16.40	0.947
19	Pilica	96	98	98	97	101	99	98	100	17.43	0.993
20	Prószków	111	110	111	109	104	110	107	105	18.46	1.058
21	Henryków	101	97	98	97	100	95	98	102	17.88	1.000
22	Kłodzko	111	116	115	107	110	104	104	104	18.23	1.026
23	Szczytna Śląska	109	104	107	106	98	105	107	106	18.60	1.057
24	Kowary	101	105	107	107	98	101	104	104	18.17	1.025
Mean (m)		1.08	2.71	4.77	7.93	10.73	13.18	15.57	17.50	17.50	–
%		100	100	100	100	100	100	100	100	–	–

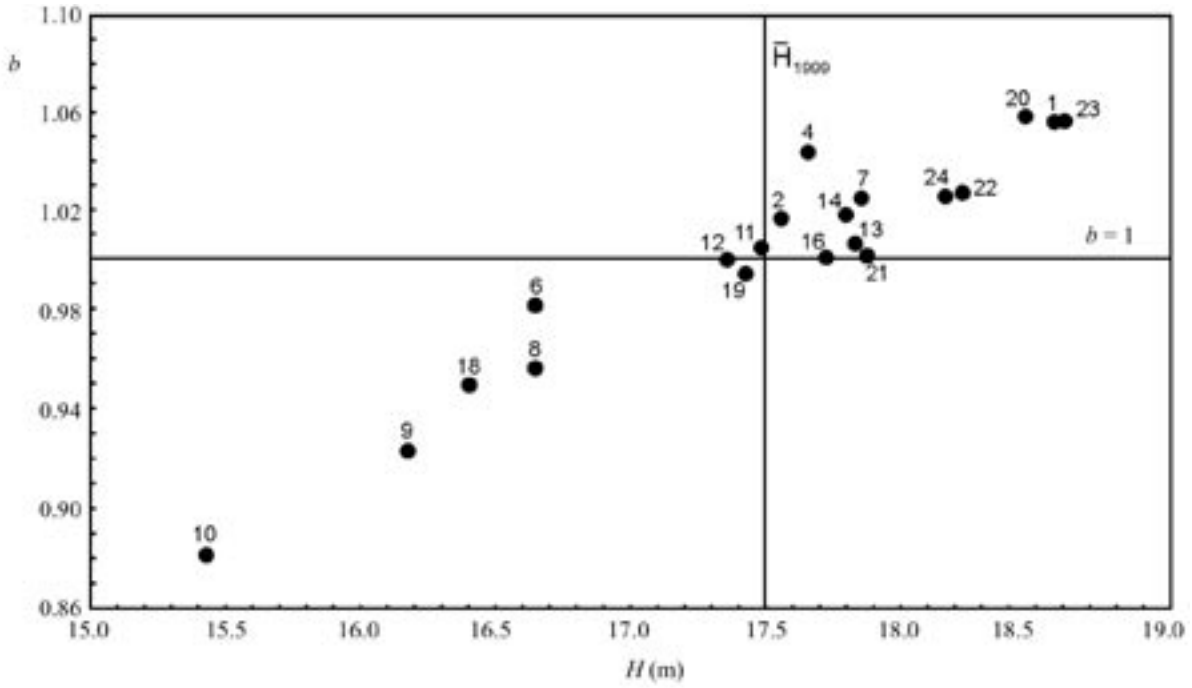

Fig. 3. Assessment of adaptation traits of larches based on adaptation index (b) and mean tree height of provenances (H) at age 35 using FINLAY-WILKINSON (1963) method; 1–24 – provenance number according to Table 1

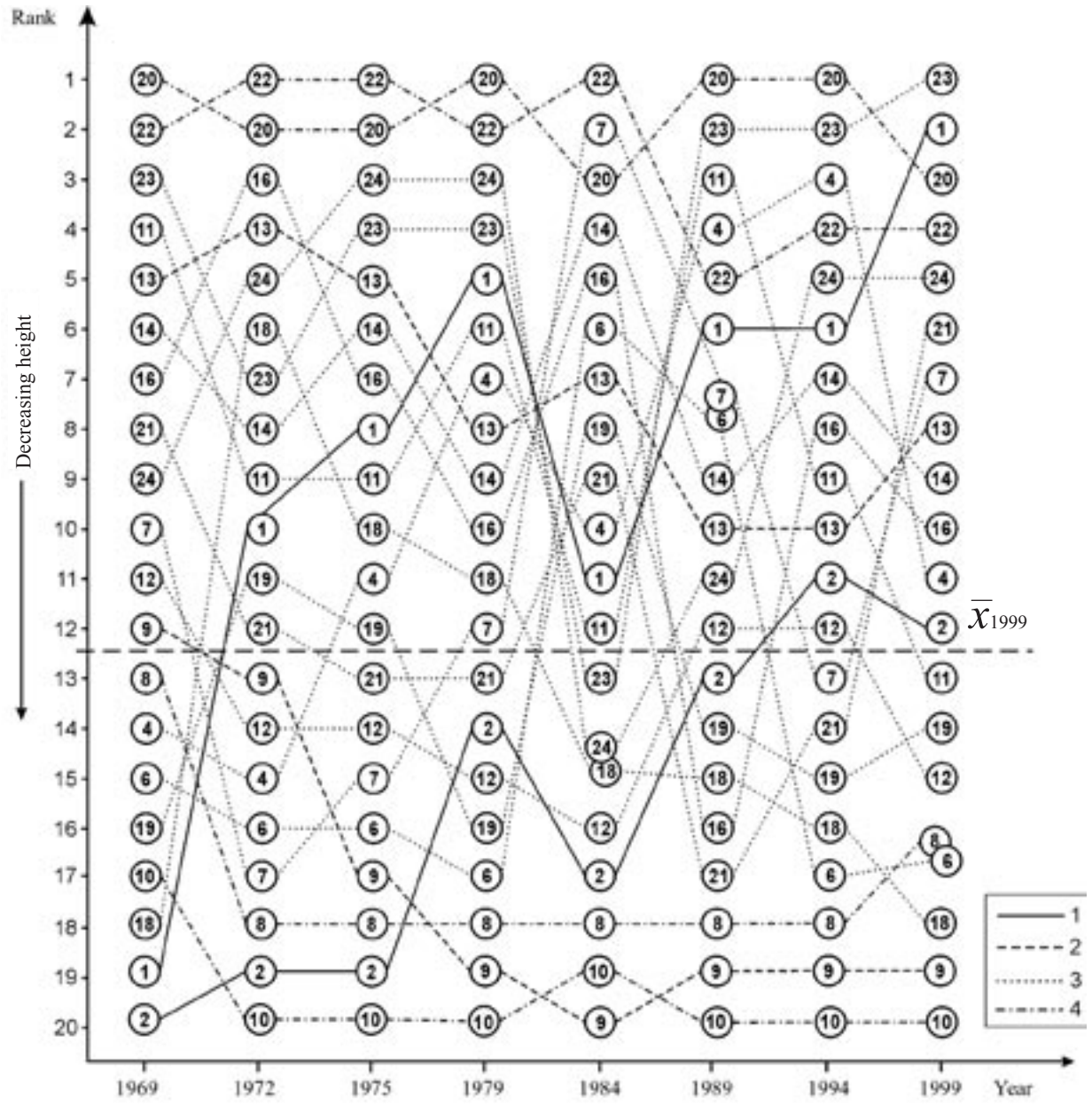

Fig. 4. Mean height: ranking position of larch provenances in successive years of growth; 1–24 – provenance number according to Table 1; effect of G × E_{age} interaction: 1 – positive, 2 – negative, 3 – change in rank, 4 – no age effect

tionship between these characteristics (*b* and *H*) two main groups of larch populations were distinguished. The first group included highly reactive and well-growing populations from Myślibórz, Pelplin, Konstancjewo – "Płonne", Czerniejewo, Świętokrzyski PN, Moskorzew, Prószków, Kłodzko, Szczytna Śląska and Kowary ($b > 1$ and *H* above average), and the other group – Konstancjewo – "Tomkowo", Rawa Mazowiecka, Grójec, Marcule, Bliżyn, Krościenko and Pilica with stability above average ($b < 1$) and height below average. Populations from Hołubla and Henryków ($b = 1$, *H* above average), and from Skarżysko ($b > 1$, *H* below average) were intermediate between these two groups (Table 2, Fig. 2).

An analysis of the effect of the G × E_{age} interaction for the basic growth trait of larch, i.e. tree height, during 1969–1999 showed that for most populations the effect of the interaction was a change in rank (Fig. 4). A positive effect of genotype and age on height growth was observed only in two northern provenances: Myślibórz Północ and Pelpin, and a clearly negative effect – in provenances from Grójec and Świętokrzyski PN. However, in the case of the latter, larches older than 30 years tended to increase its ranking position. Changes in the ranks of the provenances resulted from the combined effect of genotype and age and the interaction of both sources of variation. Provenances from Kłodzko and Prószków in the Sudetes, from Rawa Mazowiecka in Central Poland, and from Marcule situated at a fringe of the Saint-Cross Mts. have not changed their ranking position during the whole 35-year period, which might suggest that age had no significant effect on the height growth of trees.

DISCUSSION

An assessment of larch characteristics made by Finlay-Wilkinson's method (SABOR 1993) showed a high adaptation stability of larch provenances tested under the site conditions of the Beskid Sądecki Mts. However, the values of this trait tended to decrease as the mean height of trees increased. The greatest variation was observed in larches of northern provenances, smaller – in those from the Sudetes, and the smallest – in larches from the Saint-Cross Mts. The results of this study confirmed earlier reports on the high adaptation ability of larch populations from Poland, especially from some localities in the Saint-Cross Mts. and the Sudetes. The populations of these provenance regions, tested in international experiments, have been considered as plastic populations by many authors (ŠŤASTNÝ 1972; GIERTYCH 1979, 1980; WEISGERBER, ŠINDELÁŘ 1992; ŠINDELÁŘ 1996). Such populations should thus play a central part in forest management.

When analysing the effect of the "genotype × years of observation" interaction which determines the type of genetic reactivity of larch, it was found that the majority (60%) of the tested progenies of larch stands displayed the "$G \times E_{age}$" interaction with change in rank as defined by GALLAIS (1990). A positive effect of this interaction on height growth was obvious in the case of northern provenances (Myślibórz Północ and Pelplin) which distinctly improved their ranks with age. A negative effect was found in larches from Grójec and Świętokrzyski PN. No effect of age or its interaction with genotype was observed during 1969–1999 for the provenances in which the height growth of trees was the fastest (Kłodzko and Prószków) or the slowest (Marcule and Krościenko). This makes it possible, especially in the case of these groups of provenances, to conduct effective selection in the early stage of tree growth, which would bring a permanent genetic gain.

The provenances from the northern part of Poland (little known and not tested hitherto), particularly larch from Myślibórz, deserve special attention. This population exhibits high growth dynamics and high adaptation ability not only in the Beskid Sądecki Mts. (KULEJ 2001) but also on the other experimental plots of the 1967 All-Poland Larch Provenance Experiment (ANDRZEJCZYK, BELLON 1999; MATRAS et al. 2001). Great differences in this respect between the progenies of two neighbouring larch stands, i.e. Konstancjewo – "Płonne" and Konstancjewo – "Tomkowo", indicate that larch populations of different genetic and silvicultural value are mixed with each other not only at the level of the whole country or natural forest regions, but also within a single forest district or a group of neighbouring stands. This diversity may be explained by the fact that larch in Poland occurs in the form of isolated islands and its cultivation has long been popular, which resulted in both the mixing of native ecotypes and the introduction of seeds of foreign origin (BAŁUT 1967; BORATYŃSKI 1986). The results of this study provided new information on the location of larch provenances which should be used more widely than before.

CONCLUSIONS

Larch of the populations tested in Krynica exhibited a high stability under the conditions of the Beskid Sądecki Mts. However, stability tended to decrease with increasing mean height of trees.

The lack of the effect of age or its interaction with genotype on the growth of larch of the provenances showing extreme values of tree height suggests that it would be possible to carry out effective selection in the early stage of growth, which will ensure a permanent genetic gain.

The results of this study provided new information on the location of larch provenances which should be used in forestry on a wider scale. These mainly include provenances from northern Poland, which are little known and have not been tested hitherto. It is thus possible to extend the seed base of larch in Poland, also by using artificial populations of unknown origin.

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Received for publication May 11, 2004
Accepted after corrections May 29, 2004

Adaptace modřínu (*Larix decidua*) polských proveniencí v horských podmínkách pohoří Beskid Sądecki (jižní Polsko)

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ABSTRAKT: V dlouhodobém šetření prováděném v rámci Celopolského provenienčního pokusu s modřínem jsme ve stanovištních podmínkách pohoří Beskid Sądecki (na pokusném objektu Krynica) sledovali genetickou variabilitu u 20 polských proveniencí modřínu. Šetření spočívalo v měření výšky stromu u jednotlivých populací modřínu v letech 1969–1999, tj. ve stáří stromů 5, 8, 11, 15, 20, 25, 30 a 35 let. Výsledky naznačily značnou adaptační stabilitu proveniencí testovaných na objektu Krynica. Tato stabilita však měla s rostoucí průměrnou výškou stromů tendenci klesat. Hodnocení efektu interakce „genotypu (provenience) s ročníky sledování (věkem)" ukázalo vysokou stabilitu výškového růstu u populací modřínu s extrémně vysokými hodnotami tohoto znaku. Ze studie vyplývá, že zejména v případě posledně uvedené skupiny proveniencí lze v rané fázi růstu provádět účinnou selekci a zajistit tak trvalý genetický přínos.

Klíčová slova: modřín opadavý; provenience; genotyp; výsadbový pokus; Beskydy; Polsko

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