Selection of European larch provenances based on productivity and economic values

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ABSTRACT: Productivity of individual European larch provenances was evaluated on the basis of height and diameter growth and volume production at the age of 40 years. This work was focused on identifying differences among European larch provenances using a growth simulation model (SIBYLA). Based on the growth simulations, all selected provenances had greater mean height, stem diameter and stem volume at the age of 120 years than the control seed source. Provenance 49 (Krnov-Loučky, Jeseníky, CZ) had the greatest height growth and volume, but it ranked the fourth in diameter. Provenances 16 (Cavalese, Italy) and 71a (Jaroměřice-Chroustov, Vysočina, CZ) ranked the highest in stem diameter and volume growth. With respect to a different tree number per hectare these characteristics are different when expressed as total per-hectare volume production. Despite that fact, the control material is inferior also in this category. In addition to production, timber assortment and economic balance of the same provenances at the age of 120 years were evaluated.

Keywords: growth; production; forest tree breeding

Forest tree species are generally characterized by a high degree of intraspecific genetic variability and heritability is relatively high for many commercially important traits (Cornelius 1994), which provides opportunities for economically effective breeding procedures.

As expected, the economic effectiveness of breeding is influenced to a great extent by preferred breeding activities or their combinations (Thompson et al. 1989; Palmer et al. 1998).

Another criterion influencing the economic effectiveness of breeding is the rotation age in forestry practice. In many cases the rotation length is determined by ecological or social aspects that do not mostly correspond with economic goals and thus decrease the overall economic effectiveness (Löfgren 1988).

As a frequent method of economic evaluation of forest tree breeding some studies utilize changes in biological growth models, precisely changes in growth function values (Johansson, Löfgren 1985). These changes in growth parameters are then converted to cash values (Fins, Moore 1984).

Traditional selection systems in forestry rely on the selection of trees at relatively young ages, usually less than the half rotation age. Tree improvement studies usually show a strong age correlation and genetic gain estimated at selection age is often assumed to be highly correlated with gain at rotation age (Lamberth et al. 1983; Falconer, Mackay 1996).

Growth models and simulators are an alternative to traditional predictions of genetic gain. The models simulating the stand development can be used to assess differences among progenies at a relatively young age and thus estimate a selection differential and genetic gain at rotation age. Prediction of gain in terms of production at rotation age is crucial to evaluate the effectiveness of initial investments into breeding measures.

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Jansson (2007) examined the relationship between height at an early age (one third of the rotation period) and volume production in block-plots at older ages. Based on the parent breeding values, the selection of 25% of the best parents gave a gain of 25% in volume per hectare compared with unimproved check lots.

Growth models used in forestry research offer a useful tool for breeding effectiveness evaluation with respect to the economic return of resources invested into these measures. However, until recently, only few models allowed the inclusion of genetic effects. Buford and Burkhard (1987) studied the inclusion of genetic effects in growth models. They concluded that the addition of genetic gains from provenances or progeny selection does not require any intensive structural change of the applied models. Indications are that by choosing the height curve carefully, differences in development among seed sources and families on a given site can be modelled by altering the level of the height-age curve. Inclinations of these curves can be altered on the basis of forest stand quality and planting scheme. The main objective of this study is a prediction of growth and economic parameters at the age of 120 years (end of rotation) on the basis of repeatedly measured parameters at the age of 7, 17, 22 and 40 years.

MATERIAL AND METHODS

The study was conducted in the framework of a long-term provenance trial established in 1961 as part of the international IUFRO series. The test plantation was established in the demonstration forest enterprise in Kostelec nad Černými lesy near the breeding station and experimental nursery operated by Faculty of Forestry and Wood Sciences, Czech University of Life Sciences in Prague. The plot is located 365 m above sea level on a gentle slope (1.5–2.5%) with a slight northern exposure. The vegetation period lasts 166 days; mean annual temperature is 7.7°C; annual precipitation is 697 mm. The bedrock is predominantly composed of sandstone and conglomerate rock. The local soil type is loess clay.

The production of autochthonous as well as allochthonous European larch trees of Austrian, Italian, French, Romanian, Slovakian and Czech provenance was compared in the test. A total of 28 provenances were planted in March 1961. Provenance numbers and origins are listed in Table 1. Seedlings in the test plantings were planted at a 2 × 2 m spacing. Subplots were established in standardized 22 × 22 m dimensions with 121 seedlings on one single subplot. The total area of the research plot was 1.35 ha. At present, approximately a third of the original trees is present on the research plot.

At the age of 40 years height growth, diameter growth and volume production of the trees were evaluated. Measurements were performed at the end of the growing season in October 2001. Tree heights were measured with an ultrasound hypsometer (Vertex III, Haglöf Sweden AB, Sweden). Tree heights were measured to the nearest 0.1 m.

Trunk diameters were measured at breast height (1.3 m) at 90° angle to the stem axis with stem callipers (Kinex). This calliper has 1 mm accuracy. Two perpendicular calliper measurements were recorded and averaged. Studied progenies on the evaluated experimental plot were compared with open pollinated larch plantations grown under the same site conditions. The UNISTAT statistical software was used for a statistical analysis of data. Basic descriptive statistics such as number of valid observations, arithmetic mean, standard deviation and coefficient of variation were determined for each evaluated provenance. After checking the data for normality and homogeneity of variance one-way ANOVA was later used for mathematical and statistical assessment of measured biometric characteristics of obtained data.

Mean stem volume was defined according to the tables of Grundner-Schwappach (2012). Stem diameters were categorized into 1-cm diameter classes and then tree heights were plotted against classified diameters in a height diagram, in which a curve was fitted. According to this curve to each diameter class an appropriate height was determined. Based on these values a volume for each diameter class was derived from the Grunder-Schwappach tables. This volume value was finally multiplied by the number of trees within a corresponding class. By summarizing class volumes and dividing by the number of trees within provenances the mean stem volume of each provenance was calculated.

In order to estimate the projected value of provenance selection at rotation age (120 years) we modelled the development of volume value and economic production using a forest bio-dynamic simulator (SIBYLA) (Fabrika 2005; Fabrika, Ďurský 2005).

Derivation of model productions was performed in the following steps:
– generating of forest stand structure,

Table 1. List of European larch provenances, Truba locality, Kostelec nad Černými lesy

Provenance			Area of origin	Provenance group
No.	designation	country of origin		
2	Schönwies	Austria	Inner Alps	Tyrol
7	Langau	Austria	Northern intervening Alpine zone	Northern Alps
8	Semmering	Austria	Northern intervening Alpine zone	Northern Alps
9a	Lammerau	Austria	North-Eastern margin of Alps	North-Eastern Alps
15	Bruneck-Ahrntal	Italy	South Tyrol	Tyrol
16	Cavalese	Italy	South-Eastern margin of Alps	South-Eastern Alps
17	Pergine-Laresotti	Italy	South-Eastern margin of Alps	South-Eastern Alps
18	Tenna	Italy	South-Eastern margin of Alps	South-Eastern Alps
19	Pergine-Selvot	Italy	South-Eastern margin of Alps	South-Eastern Alps
21	Pragelato	Italy	South-Western Alps	South-Western Alps
23	Embrum-Aigulles	France	Western French Alps	South-Western Alps
26	Briancon	France	Western French Alps	South-Western Alps
34	Neumünster	Germany	Schleswig-Holstein	Unknown origin
37	Krnov-Hošťálkovy	CZ	Jeseníky (foothills)	Jeseníky-autochthonous
39	Zábřeh-Dubicko	CZ	Zábrežany Crystal Massive	Jeseníky-autochthonous
40	Ruda nad Moravou	CZ	Jeseníky (foothills)	Jeseníky-autochthonous
47	Blühnbachtal	Austria	Northern intervening Alpine zone	North-Eastern Alps
49	Krnov-Loučky	CZ	Nízky Jeseník and Oderské vrchy	Jeseníky-autochthonous
50	Krnov-Radim	CZ	Jeseníky (foothills)	Jeseníky-autochthonous
51	Čierny Váh-Ipoltica	Slovakia	Nízké Tatry	Slovakian Nízké Tatry
53	Smokovec	Slovakia	Vysoké Tatry	Slovakian Vysoké Tatry
54	Bischofswiesen	Germany	Northern intervening Alpine zone	North-Eastern Alps
59	Brezovička	Slovakia	Levoča Highlands	Slovakian Šariš larch
64	Janovice-Stará Ves	CZ	Vysoký Jeseník	Jeseníky -autochthonous
67	Staré Hory	Slovakia	Veľká Fatra	Slovakian Nízké Tatry
71	Piatra Arse	Romania	Carpathians Transylvanian Alps	Romanian larch
71a	Jaroměřice-Chroustov	CZ	Czech-Moravian Highlands	Jeseníky-autochthonous
A	Hradec nad Odrou	CZ	Nízky Jeseník and Oderské vrchy	Jeseníky-autochthonous

– generating of quality and damage representation,
– generating of tree coordinates,
– growth model,
– calculation of production characteristics.

Generating of forest stand structure

From the input data (mean diameter, mean height, volume per hectare, age) an initial number of trees per hectare (*n*) was calculated dividing volume per hectare by mean stem volume (*v*).

Mean stem volume was calculated from a volume equation (Petráš, Pajtík 1991) based on mean diameter and mean height. Using mean diameter (d_g) and coefficient of variation of diameters (s_d *%)* coefficients of the diameter frequency function were derived. In the SIBYLA model the Weibull frequency function is used to calculate the presence of tree diameter on the basis of initial tree number (*n*) and width of diameter class (1 cm). Using the obtained frequency distribution of trees, diameters were deduced by means of repeated occurrence of a certain diameter according to its frequency. The model calculated corresponding heights to diameters from the appropriate volume function (equation) for European larch. Heights of individual trees were derived from a mathematical model (Šmelko et al. 1987) based on mean height (h_g) and mean diameter (d_g). Volume per hectare was derived (V_0) from the tree number and volumes of individual trees, and it was later compared with the initial input per-hectare volume (*V*). In case that the input volume was equal to the derived volume, the process of diameter generating was terminated. In other cases this iterative process goes on until both variables are equal. The iteration increases or decreases the tree number by one unit (tree) in dependence on a difference between input and derived volume.

Generating of quality and damage representation

The model is based only on age (t) and mean height (h_g) of tree species. On the basis of these inputs, the information about the proportion of qualitative classes (*% qual*) and the proportion of damaged trees ($\% \, d_{mg}$) in the forest stand is generated. The method is based on relationships between age and damage, and between site class (q) and quality derived for the purposes of the construction of assortment yield tables (Petráš et al. 1996). The tables were published by Halaj et al. (1990):

$$\% \, d_{mg} = a + b \times t^c \qquad (1)$$

$$\% \, qual = a + b \times q^c \qquad (2)$$

where: a–c – coeficients

Site class (absolute height site class at the age of 100 years) is derived from the site class multi-curve diagram of yield tables (Halaj et al. 1987):

$$q = f(t, h_g) \qquad (3)$$

Generating of tree coordinates

The process of tree coordinate generation is accomplished in two steps. The first step of generating the macrostructure, thus describing a species mix, was not employed, because a modelled larch stand was homogeneous. In the second step a specific microstructure was modelled based on the probability of tree distance. The modelling process is fully stochastic. A detailed description of tree coordinate generation as well as other characteristics (generating of diameter; shape and height of canopy and also an alternative comparative model) can be found in Fabrika (2005).

Growth model

In the SIBYLA growth simulator stand quality is used instead of forest stand (cover) quality. Stand quality is evaluated directly by ecological properties such as climate, atmosphere and soil. The SIBYLA growth simulator uses a model of ecological quality assessment of SILVA 2.2 growth simulator, which was described by Kahn (1994). The following stand variables were employed by the simulator:

– NO_X atmosphere concentration (ppb),
– CO_2 atmosphere concentration (ppm),
– available soil nutrition (relative value within 0 to 1 interval),
– days of growing season (number of days with temperature above 10°C),
– annual range of temperatures (difference between min. and max. temperature within a year in °C),
– average daily temperature in the vegetation period in °C (April to September),
– soil moisture (relative value within 0 to 1 interval),
– amount of precipitation during the growing season in mm (April to September),
– index of aridity (de Martonne).

The same values of stand variables defined by estimates for the respective region were used for all simulations.

Calculation of production characteristics

With respect to omitting thinning in the model, characteristics of the secondary (thinning) stand were not taken into account. That concluded in equal values of the main and compound forest stand that were not therefore evaluated separately.

Tree volume

Tree volume was calculated from equations published by Petráš and Pajtík (1991). Input parameters are tree diameter (d), tree height (h) and coeficients (a). For production evaluation by SIBYLA growth simulator stem volume underbark is used. Volume equation for European larch:

$$v = a_1(d + 1)^{a2} \times h^{a3} - a_4(d + 1)^{a5} \times h^{a6} \qquad (4)$$

Mean diameter – derived as a quadratic mean of summed diameters of all trees (d_i):

$$d_g = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n}} \qquad (5)$$

Variability of diameters – calculated as a standard deviation of diameters of all trees (d_i):

$$s_d = \sqrt{\frac{\sum_{i=1}^{n} (d_i - \overline{d})}{n}} \qquad (6)$$

Mean height – calculated as an arithmetic mean of all heights (h):

$$h_s = \frac{\sum_{i=1}^{n} h_i}{n} \quad (7)$$

Volume – total volume of all trees (v_i) in a given area (p):

$$V = \frac{\sum_{i=1}^{n} v_i}{p} \quad (8)$$

Per-hectare squared diameter – obtained by the summation of squared breast height diameters of all trees (d_i), surface area of simulated stand(p):

$$G = \frac{\frac{\pi}{4}\sum_{i=1}^{n} d_i^2}{p} \quad (9)$$

Mean stem value – calculated as a ratio of volume (V) and tree number (N):

$$\bar{v} = \frac{V}{N} \quad (10)$$

Total volume production (TVP) – expresses the sum of main stand volume at age t ($V_{H(t)}$) added to the sum of all thinnings (volume) up to age t (including) ($V_{P(i)}$).

$$TVP_t = V_{H(t)} + \sum_{i=1}^{t} V_{P(i)} \quad (11)$$

Total periodic increment (TPI) – calculated as a difference in total volume productions (TVP_t)at two stages divided by the length of the period (Δt = standard value is 5 years):

$$TPI_t = \frac{\frac{TVP_t - TVP_{t-\Delta t}}{\Delta t} + \frac{TVP_{t+\Delta t} - TVP_t}{\Delta t}}{2} \quad (12)$$

Total mean increment (TMI) is calculated as TVP divided by age (t):

$$TMI_t = \frac{TVP_t}{t} \quad (13)$$

Timber assortment – estimates of forest incomes are based on timber assortment into 7 quality and 6 diameter classes. Quality classes are divided according to potential assortment utilization: I, II, IIIA and IIIB, IV, V, VI. Diameter classes (round timber I-III) classification according to mid-length diameter: class 1 (16–19 cm), class 2 (20–29 cm), class 3 (30–39 cm), class 4 (40–49 cm), class 5 (50–59 cm), class 6 (60 and more cm).

Timber assortment estimates were derived from tables (Petráš, Nociar 1990, 1991).

Rough yield estimate – based on represented volumes of specific assortments (v_j) and diameter classes expressed in CZK (c_{ij}):

$$F_{ij}^{+} = v_{ij} \times c_{ij} \quad (13)$$

$$F^{+} = \sum_{i=1}^{7} \sum_{j=1}^{6} F_{ij}^{+} \quad (14)$$

For the derivation of value market prices of various timber assortments according to diameter classes were employed.

Net yield – calculated as rough yield estimate (F_t^{+}) minus total direct costs (F_t^{-}). These total direct costs are equal to the values set up implicitly in the SIBYLA growth simulator.

$$Yield_t = F_t^{+} + F_t^{-} \quad (15)$$

Total value production (tvp) – computed as the sum of main stand rough yield estimates at age t ($F_{H(t)}^{+}$) added to the sum of all the rough yield estimates from thinnings up to age t (including) ($F_{P(i)}^{+}$):

$$tvp_t = F_{H(t)}^{+} + \sum_{i=1}^{t} F_{P(i)}^{+} \quad (16)$$

Total periodic value increment ($TPVI$) – calculated as a difference in total value productions (tvp) at two stages divided by the length of the period (Δt – standard value is 5 years):

$$TPVI_t = \frac{\frac{tvp_t - tvp_{t-\Delta t}}{\Delta t} + \frac{tvp_{t+\Delta t} - tvp_t}{\Delta t}}{2} \quad (17)$$

Total mean value increment ($TMVI$) – calculated as total value productions (tvp) divided by age (t):

$$TMVI_t = \frac{tvp_t}{t} \quad (18)$$

Total economic production (TEP) – expresses the sum of net yields of main stand at age t added to the sum of net yields within secondary (thinning) stand during growth simulation run (indirect costs included) plus total incomes (F_0^{+}) and costs (F_0^{-}) realized before the growth simulation was launched:

$$TEP_t = yield_{H(t)} + \sum_{i=1}^{t}\left[F_{P(i)}^{+} - F_{P(i)}^{-} \times \left(1 + \frac{\%indir \times costs}{100}\right)\right] + $$
$$+ F_0^{+} - F_0^{-} \quad (19)$$

Total periodic economic increment ($TPEI$) – calculated as a difference in total economic productions (TEP) at two stages divided by the length of the period (Δt – standard value is 5 years):

$$TPEI_t = \frac{\frac{TEP_t - TEP_{t-\Delta t}}{\Delta t} + \frac{TEP_{t+\Delta t} - TEP_t}{\Delta t}}{2} \quad (20)$$

Total mean economic increment (*TMEI*) – calculated as total economic production (*TEP*) divided by age (t):

$$TMEI_t = \frac{TEP_t}{t} \qquad (21)$$

RESULTS

Numbers of individual trees within the plot; basic biometric traits such as height, diameters and derived volume characteristics of European larch provenances are outlined in Table 3. These data and their descriptive statistics were assessed by Kobliha et al. (2010) according to standard methodology. Statistical significance of differences among provenances in observed traits was evaluated by ANOVA.

Results are shown in Table 2. This work was focused on detecting differences among European larch provenances using the SIBYLA growth simulator. Based on the growth projection model, all selected provenances had greater productivity (mean height, diameter, and stem volume) than the control seed source at the age of 120 years. Provenance 49 (Krnov-Loučky, Jeseníky, CZ) had the greatest height and volume growth among the seed sources tested, but it ranked only as the fourth in diameter. Provenances 16 (Cavalese, Italy) and 71a (Jaroměřice-Chroustov, Vysočina, CZ) ranked the highest for diameter and volume growth. Nevertheless, the Italian provenance ranked near the middle in terms of height growth. Provenances 7 (Langdau, Austria), 8 (Semmering, Austria) and 47 (Blühnbachtal, Austria) had the smallest breast height diameter and also volume. Provenances 47, 21 (Pragelato, Italy) and 71 (Piatra Arse, Romania) were ranked closely above the control material.

Provenance rankings changed when expressed as per-hectare volume since tree density varied by provenance. Nevertheless, the control material is rather inferior also in this category. Two selected provenances – 16 (Cavalese, Italy) and 71 (Piatra Arse, Romania) had lower per-hectare volume productivity than the control seed source. In contrast, provenance 40 (Ruda nad Moravou, Jeseníky, CZ), 17 (Pergine-Laresotti, Italy) and 9a (Lammerau, Austria) ranked the highest in terms of total per-hectare volume production.

The Austrian and Italian provenances also ranked high when the model accounted for timber product classes and net economic value (Tables 3–5).

The selected European larch provenances consistently produced a greater proportion of higher value timber products than the control seed source. Provenances 71a, 17 and 49, which were

Table 2. Analysis of variance of individual provenances

Source of variation	Sum of squares	Degrees of freedom	Mean squares	*F*	*P*
Dependent variable – tree height (m)					
Main effects	1,164.122	27	43,116	9,496	0,0000
Tree number	1,164.122	27	43,116	9,496	0,0000
Explained	1,164.122	27	43,116	9,496	0,0000
Residual	3,691.214	813	4,540		
Total	4,855.336	840	5,780		
Dependent variable – $d_{1.3}$ (cm)					
Main effects	2,836.931	27	105,072	3,607	0,0000
Tree number	2,836.931	27	105,072	3,607	0,0000
Explained	2,836.931	27	105,072	3,607	0,0000
Residual	23,685.053	813	29,133		
Total	26,521.984	840	31,574		
Dependent variable – tree volume (m^{-3})					
Main effects	7,184	27	0,266	4,373	0,0000
Tree number	7,184	27	0,266	4,373	0,0000
Explained	7,184	27	0,266	4,373	0,0000
Residual	49,466	813	0,061		
Total	56,651	840	0,067		

Table 3. Productivity of European larch provenances grown at Truba, Kostelec nad Černými lesy, Central Czech Republic

Provenance	Country	No. of trees	Heights (m)				Diameters (cm)				Volume (m^3)	Total volume (m^3)	Total volume per hectar
			7 yr	17 yr	22 yr	40 yr	7 yr	17 yr	22 yr	40 yr	40 yr		
2	Austria	30	5.00	11.90	13.50	23.20	5.30	13.30	15.50	24.70	0.59	17.7	365.70
7	Austria	44	5.50	13.20	13.80	23.40	5.50	14.30	15.90	22.20	0.49	21.56	445.45
8	Austria	46	5.70	11.70	12.80	22.60	5.20	12.60	14.70	21.90	0.45	20.7	427.685
9a	Austria	28	5.60	14.10	14.60	24.80	6.00	15.10	17.60	27.20	0.72	20.16	416.52
15	Italy	33	7.20	13.30	13.70	25.40	6.20	14.10	16.00	24.90	0.64	21.12	436.36
16	Italy	15	4.90	12.30	13.70	24.10	5.30	13.70	16.00	28.20	0.75	11.25	232.43
17	Italy	33	5.80	13.50	14.30	23.40	6.80	14.90	17.40	27.50	0.66	21.78	450.00
18	Italy	26	5.00	11.90	13.50	23.00	5.70	13.70	16.20	26.80	0.63	16.38	338.42
19	Italy	39	5.60	13.00	13.60	22.90	6.30	14.60	16.60	24.50	0.55	21.45	443.18
21	Italy	30	4.10	10.70	11.60	21.10	4.40	12.20	13.50	22.80	0.45	13.5	278.92
23	France	31	4.20	11.80	12.70	23.50	4.40	13.30	16.20	25.20	0.62	19.22	397.10
26	France	35	4.40	10.80	12.00	22.70	4.80	13.40	15.60	24.10	0.55	19.25	397.72
34	Germany	25	5.50	13.20	14.10	23.10	5.70	13.50	15.20	25.70	0.61	15.25	315.08
37	CZ	29	5.40	12.50	12.90	24.50	5.00	13.30	14.40	25.10	0.66	19.14	395.45
39	CZ	28	5.60	13.70	15.20	24.90	5.40	13.30	16.70	25.50	0.65	18.2	376.033058
40	CZ	28	6.00	14.00	15.00	26.20	5.90	14.60	17.00	27.00	0.77	21.56	445.454545
47	Austria	40	5.10	11.50	12.60	21.70	5.30	13.70	14.80	22.20	0.44	17.6	363.636364
49	CZ	22	5.30	14.60	15.40	26.10	5.10	14.00	16.40	28.00	0.8	17.6	363.636364
50	CZ	29	5.30	12.70	13.70	24.20	4.80	12.30	14.80	24.90	0.62	17.98	371.487603
51	Slovakia	28	4.90	14.30	15.80	24.60	4.60	13.50	17.30	25.30	0.64	17.92	370.247934
53	Slovakia	32	5.40	12.30	13.20	22.80	5.10	12.80	15.40	23.50	0.53	16.96	350.413223
54	Slovakia	27	5.20	12.40	12.90	24.40	5.30	12.90	15.20	24.50	0.59	15.93	329.132231
59	Slovakia	27	4.80	11.50	12.70	23.20	4.90	13.50	16.50	25.70	0.59	15.93	329.132231
64	CZ	31	5.60	11.30	13.90	24.20	5.60	12.40	15.90	24.90	0.62	19.22	397.107438
67	Slovakia	24	4.80	11.50	12.70	23.30	4.40	12.90	14.90	25.10	0.58	13.92	287.603306
71a	CZ	29	5.70	13.20	14.60	24.00	6.30	15.80	18.60	29.20	0.72	20.88	431.404959
71	Romania	21	4.10	9.80	12.20	22.30	4.30	12.40	14.00	24.10	0.55	11.55	238.636364
A	CZ	31	6.50	14.50	15.40	24.50	6.60	14.20	16.20	25.20	0.64	19.84	409.917355
Mean			5.29	12.54	13.64	23.72				25.21	0.61		

already mentioned earlier, exhibited the highest rate of first class assortments. Based on the product value, provenances number 8 (Semmering, Austria), 53 (Smokovec, Slovakia) and 47 (Blühn-bachtal, Austria) ranked relatively low and were only slightly superior to the control material.

Provenance rankings based on volume in each product class were also reflected in the product value in each class at the age of 120 (Table 6). Rankings based on total net revenue, in contrast, provided a different result (Table 7). Only two of the above-mentioned superior provenances kept the leading positions – 17 (Pergine-Laresotti, Italy) and 40 (Ruda nad Moravou, Jeseníky, CZ). The third position is occupied by Provenance 26 (Briancon, France). It is evident that the ranking of net yields projects a situation in the total volume production of provenances.

In terms of net revenue obtained per ha all of the evaluated provenances, with the exception of provenance no. 16 (Cavalese, Italy), outperformed the control (standard) material. The ranking of provenances with respect to economic balance according to the profit they potentially generate reflects the assortment ranking to a large extent.

DISCUSSION AND CONCLUSIONS

Comparing our results with other sources in the literature raises many questions, because studies of

Table 4. Predicted production of European larch provenances at the age of 120 years, based on a forest bio-dynamic model (SIBYLA)

Provenance	Diameter (cm)	Height (m)	Stem volume (m^3)	Stand density ($trees \cdot ha^{-1}$)	Total volume production ($m^3 \cdot ha^{-1}$)
2	37.3	31.44	1.23741	568	703
7	33.9	31.80	1.06458	724	771
8	33.0	30.85	0.98212	784	770
9a	39.7	33.19	1.47271	540	795
15	37.1	33.98	1.34092	580	778
16	42.9	32.12	1.61426	328	529
17	39.6	31.63	1.38640	580	804
18	41.3	31.49	1.47852	440	651
19	35.9	31.07	1.14817	656	753
21	37.6	29.84	1.16119	584	678
23	38.4	31.85	1.32544	520	689
26	37.2	31.35	1.22491	648	794
34	39.5	31.35	1.36226	546	621
37	38.1	32.73	1.35427	544	737
39	38.0	33.14	1.35955	536	729
40	38.9	34.35	1.49148	540	805
47	34.9	29.48	1.02727	680	699
49	41.2	34.49	1.64069	420	689
50	38.2	32.49	1.34257	524	704
51	38.4	32.99	1.37889	496	684
53	36.2	31.05	1.15754	596	690
54	37.4	32.69	1.31043	532	697
59	38.9	31.21	1.32357	488	646
64	36.8	32.36	1.25447	616	773
67	39.5	31.60	1.37178	472	647
71	39.7	30.56	1.33690	424	567
71a	42.5	32.43	1.60900	480	772
A	37.8	32.81	1.34057	580	778
K	29.5	23.86	0.59177	1020	604

Table 5. Predicted timber assortment of European larch provenances at the age of 120 years, based on a biodynamic simulation model (SIBYLA) (in m^3)

	Timber volume by quality classes at the age of 120 years							
Provenance	I	II	IIIA	IIIB	I-IIIB	V	VI	waste
2	53.68	63.64	263.8	209.2	590.32	87.56	24.76	0.2
7	44.2	74.6	295.12	217.72	631.64	111.4	27.4	0.28
8	31.48	77.76	297.44	218.32	625	116.72	27.92	0.32
9a	78.4	62.48	283.84	243.96	668.68	97.44	28.92	0.28
15	51.68	80.16	298.6	230.72	661.16	91.56	24.92	0.12
16	66.56	33.56	184.52	169.44	454.08	56.68	18.6	0.12
17	84.92	57.4	282.92	256.96	682.2	93.36	28.44	0.2
18	76.08	45.2	227.84	211.08	560.2	68.52	21.8	0.08
19	47.52	66.88	283.72	227.72	625.84	100.08	27.04	0.24
21	59.12	58.04	251.96	200.08	569.2	84.52	24.16	0.24
23	54.96	55.44	257.88	218.84	587.12	79.2	22.88	0.08
26	64.56	74.16	293.84	234.12	666.68	99.44	27.36	0.24
34	66.04	51.12	227.44	184.8	529.4	70.56	21.12	0.16
37	63.32	58.04	279.2	226.24	626.8	85.88	23.92	0.12
39	52.32	68.44	252.44	225.08	598.28	101.04	29.08	0.36
40	74.08	68.68	286.04	248.68	677.48	98.6	29.04	0.24
47	42.76	62.8	266.48	205.24	577.28	97.36	23.72	0.2
49	84.6	54.96	250.2	212.44	602.2	66.2	20.72	0
50	567.6	62.32	251.6	223.56	594.24	85.24	23.84	0.12
51	51.48	61	238.76	208.96	560.2	95.44	27.8	0.4
53	41.28	62.48	255.16	207.52	566.44	96.76	26.28	0.32
54	50.6	68.8	263.48	208.52	591.4	82.88	22.76	0.12
59	71.76	52.4	233	194.56	551.72	72.72	21.28	0.12
64	57.76	77.16	289.8	227	651.72	94.64	26.24	0.2
67	73.64	51.8	240.96	192.76	559.16	68.16	20.16	0.04
71	67.36	43.64	204.52	170.96	486.48	61.88	18.4	0.08
71a	95.52	51.68	262	251.92	661.12	83.24	27.72	0.16
A	65.8	71.04	284.64	235	656.48	94.28	26.6	0.16
K	15.76	46.88	218.88	178.08	459.6	119.96	23.8	0.28

this scope (use of growth simulators in provenance research) have seldom been performed yet and existing studies are mostly of a regional character. A growth model for European larch based on stand characteristics was explored in Poland by Bruchwald et al. (2011).

Data on each forest stand in all the Forest Districts in Poland (about 2.5 million stands) were extracted from the State Forests Information System (SILP). These data were used to predict the development of timber resources and to derive growth models that determine the possibility of harvesting timber in pre-final and final felling.

Results of predictions of European larch provenance production using a simulator of forest biodynamics (SIBYLA) show a trend of significant differences among provenances and especially between the control and selected material. This trend is likely influenced by ecotypic interspecific variability of European larch.

Outstanding characteristics were observed especially in the European larch ecotype from the Sudetes region. Promising results were also recorded in these provenances artificially grown in other locations within the Czech Republic (40 – Ruda nad Moravou, 71a – Jaroměřice-Chroustov). In this case the origin (provenance) itself was expressed and in addition, selection, transfer and cultural measures have undoubtedly influenced the quality of reproduction material.

Similar trends can be found in many literature sources in the field of European larch provenance research (e.g. Barnes 1977; Giertych 1979; Šindelář 1992, 1996; Pâques 1996).

Table 6. Values of various timber assortments at the age of 120 years (in EUR)

Provenance	I	II	IIIA	IIIB	I-IIIB	V	VI	Yield
2	8,082	8,414	23,368	12,350	52,214	2,452	495	55,161
7	6,685	9,868	26,848	12,511	55,911	3,119	548	59,578
8	4,793	10,393	27,276	12,436	54,898	3,269	558	58,725
9a	11,732	8,156	24,692	14,690	59,269	2,728	579	59,726
15	7,826	10,618	26,583	13,434	58,461	2,564	499	61,523
16	9,733	4,385	15,505	10,378	40,001	1,588	372	41,961
17	12,513	7,499	24,487	15,486	59,985	2,614	568	63,168
18	11,247	5,878	19,442	12,811	49,378	1,919	436	51,732
19	7,115	8,869	25,288	13,380	54,651	2,803	540	57,994
21	8,864	7,642	22,196	11,875	50,577	2,366	483	53,426
23	8,255	7,269	22,604	13,052	51,179	2,218	458	53,855
26	9,595	9,856	26,085	13,672	59,207	2,784	547	62,538
34	9,786	6,684	19,773	11,070	47,313	1,976	422	49,711
37	9,427	7,640	24,507	13,531	55,106	2,405	479	57,989
39	7,870	9,001	22,416	13,340	52,628	2,829	581	56,038
40	10,905	9,062	24,940	14,912	59,820	2,760	581	63,161
47	6,514	8,288	24,106	11,870	50,778	2,726	475	53,979
49	12,484	7,162	21,394	12,871	53,911	1,854	415	56,179
50	8,523	8,195	22,199	13,342	52,259	2,387	477	55,124
51	7,696	8,014	20,992	12,384	49,085	2,672	556	52,313
53	6,235	8,302	22,900	12,153	49,591	2,709	525	52,826
54	7,631	9,106	23,347	12,331	52,415	2,321	455	55,191
59	10,642	6,865	20,280	11,751	49,537	2,036	426	51,999
64	8,603	10,211	25,704	13,332	57,850	2,650	525	61,025
67	10,938	6,753	20,944	11,588	50,224	1,908	403	52,536
71	10,028	5,690	17,715	10,313	43,746	1,733	368	45,846
71a	14,128	6,675	22,253	15,457	58,512	2,331	555	61,398
A	9,746	9,419	25,092	13,938	58,196	2,640	532	61,368
K	2,407	6,231	20,408	10,202	39,248	3,359	476	43,083

Pâques (1996) evaluated growth, stem form and wood quality characteristics in a comparative provenance trial planted in Brittany in 1959. Results were in good agreement with those summarized in 20 years from two international larch provenance IUFRO experiments; that is, the high genetic variability between European larch populations and the general broad adaptability of Central European provenances. Efficient ranking of provenances could have been performed as early as in 2 years in the nursery for selection for total height.

Variation of the tree form factor and taper in European larch of Polish provenances tested under conditions of the Beskid Sądecki mountain range (southern Poland) was studied by Socha and Kulej (2007). The genetic variation in 20 provenances of European larch, growing under site conditions of the Beskid Sądecki mountain range (Krynica experimental area), was investigated during a long-term study carried out within the 1967 Polish Provenance Experiment on Larch. Data consisted of diameter measurements taken on standing trees of the analysed provenances. Results showed that there was no distinct variation in the tested larch populations in respect of stem form.

Some differences between compared provenances in respect of stem taper and form factor were the result of differences in tree height and diameter.

It is evident from these results that the selection of superior European larch provenances can significantly increase the future production of timber. It can also influence its marketing, total yields per unit area and economic profit.

Table 7. Economic balance

Provenance	Economic balance at the age of 120 years			
	yield	costs	revenue	%
		(EUR)		
2	55,161	2,293	52,869	131
7	59,578	2,515	57,063	141
8	58,725	2,812	55,913	138
9a	59,726	2,466	57,261	141
15	61,523	2,531	58,992	146
16	41,961	1,654	40,307	100
17	63,168	2,623	60,545	150
18	51,732	2,136	49,596	123
19	57,994	2,457	55,537	137
21	53,426	2,212	51,214	127
23	53,855	2,244	51,611	128
26	62,538	2,588	59,950	148
34	49,711	2,023	47,687	118
37	57,989	2,399	55,591	137
39	56,038	2,386	53,651	133
40	63,161	2,627	60,534	150
47	53,979	2,278	51,701	128
49	56,179	2,142	54,037	134
50	55,124	2,294	52,830	131
51	52,313	2,240	50,073	124
53	52,826	2,255	50,570	125
54	55,191	2,269	52,922	131
59	51,999	2,103	49,895	123
64	61,025	2,519	58,506	145
67	52,536	2,103	50,432	125
71	45,846	1,845	44,001	109
71a	61,398	2,415	58,983	146
A	61,368	2,535	58,833	145
K	43,083	2,612	40,471	100

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