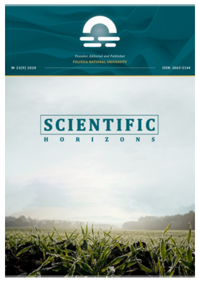
SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 26(7), 34-44



UDC 630*12: 630*181
DOI: 10.48077/scihor7.2023.34

Provenance tests of *Pinus sylvestris* L.: Estimation at the age of the half-rotation period

Yaroslav Fuchylo
Doctor of Agricultural Sciences, Professor
Malyn Applied College
11645, 1 M. Maclaii Str., Hamarnia vil., Ukraine
Institute of Bioenergy Crops and Sugar Beet NAAS
03141, 25 Klinichna Str., Kyiv, Ukraine
https://orcid.org/0000-0002-2669-5176

Yuriy Hayda
Doctor of Agricultural Sciences, Professor
Separated subdivision of National University of Life and Environmental Sciences of Ukraine
"Berezhany Agrotechnical Institute"
47500, 20 Academichna Str., Berezhany, Ukraine
Chernihiv Polytechnic National University
14027, 85 Shewchenko Str., Chernihiv, Ukraine
https://orcid.org/0000-0001-6019-9654

Ihor Ivanyuk
Doctor of Agricultural Sciences, Professor
Malyn Applied College
11645, 1 M. Maclaii Str., Hamarnia vil., Ukraine
https://orcid.org/0000-0002-4969-8783

Olga Mazhula
PhD in Agricultural Sciences
Institute of Bioenergy Crops and Sugar Beet NAAS
03141, 25 Klinichna Str., Kyiv, Ukraine
https://orcid.org/0000-0002-0241-5280

Tetiana Ivaniuk*
PhD in Agricultural Sciences, Associate Professor
Polissia National University
10002, 7 Stary Blvd., Zhytomyr, Ukraine
https://orcid.org/0000-0001-6171-4064

Article's History:
Received: 30.04.2023 Revised: 20.06.2023 Accepted: 12.07.2023

Suggested Citation:
Fuchylo, Ya., Hayda, Yu., Ivanyuk, I., Mazhula, O., & Ivaniuk, T. (2023). Provenance tests of *Pinus sylvestris* L.: Estimation at the age of the half-rotation period. *Scientific Horizons*, 26(7), 34-44. doi: 10.48077/scihor7.2023.34.

*Corresponding author

Abstract. The study of geographical crops is relevant because they are one of the reliable tools for identifying possible scenarios for the response of forest woody plant species to climate change. The purpose of the study of geographical crops of Scots pine established in 1981 in the Kyiv Oblast was to compare the growth and productivity of provenances in different age periods, determine the optimal time for early and final diagnosis of their ranking, and model the relationship between the growth and survivability indicators of provenances with climatic and other environmental variables at the age of 21, 32, and 37 years. The ANOVA method established a statistically significant influence of the geographical origin of seeds on the growth of geographical crops. At the age of 37, the capacity for survival varies from 25% (Lviv provenance) to 36.2% (Chernihiv provenance). At this age, populations from Lviv, Kyiv, and Cherkasy oblasts are characterised by the highest height. According to the intensity of radial growth, these same provenances are distinguished, as well as variants from Volyn and Luhansk. In terms of the stock of stem wood, the best is provenance from the Chernihiv Oblast. Stabilisation of the ranks of provenances in terms of survivability, growth, and productivity is observed only after 21 years. It is assumed that the most accurate assessment of the growth and condition of Scots pine provenances can be obtained at an age that corresponds to a third or a half of the age of the main felling. The trend of clinal variability in the survival of provenances and the average diameter of their trunks along the geographical (latitudinal) and ecological (temperature) gradients is revealed. The study results can be used to update the current forest-seed zoning of Ukraine

Keywords: geographical variability; growth indicators; capacity for survival; rank correlation; clinal variability

INTRODUCTION

One of the most urgent tasks of forest science is to determine the scenarios and consequences of forest adaptation to climate change. To predict such scenarios and develop mitigation measures, reliable information on the possible response of individual elements of forest ecosystems to climate change is needed. It is likely that in order to ensure effective forest reproduction in the new climatic conditions, it would be advisable to transfer more adapted forest reproductive material from other regions.

When assessing and running the dynamics of growth and stability of forest woody plants under climate change, data from the study of geographical crops are widely used, that is, experimental crops in which the offspring of geographically distant populations of a certain species that were formed under different climatic conditions are tested on a homogeneous ecological background. Therefore, measurements and surveys of such geographical crops, their analysis, carried out for a long time, allow forming a database for monitoring and predicting changes in the productivity of forest stands, to update forest-seed zoning in the context of climate change.

Studies of intraspecific variability of Scots pine in geographical cultures have more than two hundred years of history and continue in many countries of the world. Swedish researcher Andersson Gull *et al.* (2018), studying the phenology of seven-year-old Scots pine seedlings of various geographical origins, found that if the climate warms, its northern provenances may suffer from spring frosts due to the earlier beginning of the growing season. At the same time, it was found that the high genetic variability of Scots pine can provide sufficient potential for its adaptation to new climatic conditions by breeding.

Kivimäenpää *et al.* (2018) investigated the emission of biogenic volatile organic compounds from shoots and litter of four provenances of Scots pine in the northern part of its range (latitude from 58° up to 68°N). It was found that Finnish northern and southern origins differed significantly in the level and profile of volatile organic compound emissions. Matisons *et al.* (2021) in order to study the principles of climate-reasonable forest management, investigated five parallel geographical crops of Scots pine within the south-eastern Baltic region (in Latvia and Germany). Based on the assessment of the relationship between weather characteristics and growth and their heritability, it was found that the sensitivity of provenance growth can be an additional feature in the selection of forest reproductive material that is most suitable for new climatic conditions.

Barzdajn *et al.* (2016) focused on studying the variability and growth of 19 Scots pine populations in 30-year-old geographical crops in northeastern Poland. Significant interpopulation variability was found in all indicators and growth, but the greatest – in the stock of stem wood. The best in this experiment were provenances originating from the latitudinal zone between 49°N and 54°N. It is interesting that it is within this belt that the populations of Scots pine represented in the geographical cultures that were the object of our research are located.

Forests can play an important role in carbon deposition and thus contribute to reducing greenhouse gases in the atmosphere. Chmura *et al.* (2021) assessed the level of carbon sequestration by provenances of Scots pine and European spruce. It is established that there are a number of provenances that are characterised by a significantly greater ability to accumulate carbon, and therefore, it is concluded that it is possible to increase the level of carbon sequestration by breeding methods.

In a study of 57-year-old geographical crops of Scots pine in Poland by Szaban *et al.* (2023), emphasis is placed on the variability of wood density between provenances. Researchers statistically confirmed the influence of the genotype on the physical and mechanical properties of wood, in particular its density. Researchers Notivol *et al.* (2020) from Spain used data on the growth and capacity for survival of Scots pine provenances in multi-site geographical crops aged 5, 10, and 15 years to test various strategies for selecting seed sources for reforestation (seed sourcing strategies) in the context of climate change. It was found that strategies based on the selection of a single population (provenance) are preferable to strategies for using mixed seed sources.

Ballian & Šito (2017) investigated the growth and phenology of 14 European Scots pine provenances in an international experiment in Zepce in central Bosnia and Herzegovina. In these cultures, one provenance from Ukraine (from the Ivano-Frankivsk Oblast) is also tested. Differentiation of variants by capacity for survival, height, and diameter of the root neck was revealed. Memišević Hodžić *et al.* (2020) conducted their research on junior geographical Scots pine crops established in 2012 also in Bosnia and Herzegovina. It is noted that the adaptability of pine provenances is determined not only by their genetic structure, but also by the conditions of the environment in which they are cultivated. Gülcü & Bilir (2017) studied geographical culutras of Scots pine laid well south of its natural range in Turkey. It was found that almost all provenances in both test sites grow better than native species (Black pine and Taurus cedar).

Evidently, along with the traditional tasks of genecology (determining the level and scope of intraspecific variability of Scots pine by morphological, biochemical, physical, and mechanical characteristics) in trees of different ages, identifying the best populations as seed sources), the current trend of most modern studies of geographical cultures is aimed at building and using models that illustrate the conditionality of the growth and development of pine provenances by various environmental factors and developing strategies for adapting forest ecosystems to various climate change scenarios.

The purpose of the study was a comparative assessment of the growth and productivity of Scots pine provenances in geographical cultures of Scots pine near Kyiv in different age periods, determination of the optimal time for early and final diagnostics of their ranking, and modelling the relationship of growth indicators and capacity for survival of provenances with climatic and other environmental variables.

MATERIALS AND METHODS

The research was conducted on the basis of data from systematic and long-term measurements and accounting in geographical crops of Scots pine, which were created in 1981 in the Dzvonkovsky Forestry (sq. 62) at the Boyarka forest experimental station. In experimental crops, the offspring of populations from the southern part of the Scots pine range are tested on an area of 2.6 hectares (Table 1). The soil of the experimental site is sod-weakly podzolic, clay-sandy on fluvioglacial deposits, and the type of forest-growing conditions is fresh subor (B_2). Seeds for creating crops were collected in the mother plantings also in fresh subor conditions.

Table 1. *Description of the places of origin of seeds for creating geographical crops of Scots pine*

No.	Origin			Latitude (N)	Longitude (E)	Height AMSL, m	Soils
	Oblast	Enterprise	Forestry				
1	Volyn	Kovel forestry	Starovyzhivske, sq. 14	51°27′	24°31′	161	sod-medium-podzolic, gleyed sandy loam
2	Zhytomyr	Poliskyi forestry	Radynske, sq. 40	51°14′	28°52′	126	sod-medium podzolic gleyed sandy loam
3	Chernihiv	Novgorod-Siverskyi forestry	Volodymyretske, sq.10	52°07′	32°44′	145	sod-medium-podzolic sandy loam
4	Lviv	Radekhivskyi forestry	Radekhivske, sq. 41	50°13′	24°42′	221	sod-weakly podzolic sandy
5	Cherkasy	Cherkaskyi forestry	Ruskopolyanske, sq. 44	49°30′	31°59′	80	sod-weakly podzolic sandy
6	Kyiv	Boyarka FES	Dzvinkivske, sq. 47	50°16′	30°8′	190	sod-medium-podzolic sandy loam
7	Sumy	Lebedynskyi forestry	Radianske, sq. 48	50°38′	34°40′	114	grey podzolised
8	Luhansk	Kremenskyi forestry	Komsomolske, sq. 36, 42	48°32′	39°28′	110	sod-weakly podzolic

Source: *compiled by the authors*

Pine provenances were tested in geographical cultures in two repetitions. 444 seedlings of one provenance were planted in 12 rows on each plot. Layout of planting spots – 2×1 m. This design of the experiment allows carrying out tests over a long period of time. Populations of Scots pine, whose offspring are tested in geographical cultures, represent the southern part of the range of Scots pine. In this part of the range, fluctuations in the average annual air temperature between the places of seed origin are 2.1°C, and the amplitude of the growing season duration is 14 days (Table 2).

Table 2. Climatic conditions of seed origin sites

No.	Origin (Oblast)	Average annual air temperature, °C	Average annual air temperature in January, °C	Average annual air temperature in July, °C	Precipitation (May-October), mm	Sum of temperatures (May-October), °C	Duration of sunshine (May-October), hours	Duration of the growing season, days
1	Volyn	8.2	-1.9	19.1	408	2,875	1,293	206
2	Zhytomyr	8.1	-2.7	19.8	348	2,800	1,337	199
3	Chernihiv	7.1	-4.2	19.4	366	2,885	1,388	196
4	Lviv	8.3	-2.2	19.1	492	2,695	1,287	205
5	Cherkasy	8.8	-2.8	21.3	330	3,040	1,413	204
6	Kyiv	8.1	-2.9	20.0	336	3,020	1,381	204
7	Sumy	7.6	-4.1	20.2	351	2,890	1,391	194
8	Luhansk	8.9	-4.3	22.7	288	3,365	1,464	208

Source: *compiled by the authors*

The growth, productivity, and stability of Scots pine provenances were evaluated by the following indicators: tree height (H), trunk diameter at breast height (DBH), volume of wood stock per 1 ha (VOL), and % capacity for survival (Surv). The obtained data was processed by statistical modules using the STATISTICA software suite, in particular Basic Statistics and Multiple Regression. Variation analysis was performed using the Anova statistical module and the model:

$$Y_{ijk} = \mu + P_i + R_k + P_i \times R_k + e_{ijk},$$

where Y_{ijk} – *ijk*-th observation; μ – total mean; P_i – fixed effect of *i*-th origin; R_k – random effect of *k*-th replication; P_i×R_k – random effect of interaction between *i*-th origin and *k*-th replication; e_{ijk} – residual error of *ijk*-th observation.

To analyse the dynamics of growth and productivity of production, the authors used data from measurements and accounting that were carried out at the ages of 21, 32, and 37 years.

RESULTS AND DISCUSSION

One of the most important tasks in the study of geographical cultures of forest woody plant species is to assess the dynamics of ranking provenances by various parameters. As can be seen from the correlation matrix (Table 3), during the first 5-year period, the ranks of Scots pine provenances in terms of average height changed slightly, since Spearman's rank correlation coefficient was quite high r_{1-5}=0.575 and statistically significant for p<0.10. However, over the next 6 years, there were more noticeable changes in the ranks of provenances compared to annual crops (r_{1-11}=0.037), while significantly less relative to 5-year ones (r_{5-11}=0.540). An assessment of the dynamics of provenances by average height in older geographical cultures (at the age of 21, 32, 37 years) showed that the order of ranks that developed in 21-year-old cultures had little change over time. Spearman's correlation coefficients are r_{21-32}=0.673, r_{32-37}=0.661, r_{21-37}=0.794, respectively, and are statistically significant for p<0.05.

Table 3. *Matrix of Spearman's rank correlation coefficients of mean height (H) and mean trunk diameter (DBH) of pine provenances*

Variable	H1	H5	H11	H21	H32	DBH11	DBH21	DBH32
H5	0.575							
H11	0.037	0.540						
H21	0.018	0.447	0.489					
H32	0.079	0.330	0.061	0.673*				
H37	0.030	0.361	0.251	0.794**	0.661*			
DBH21						-0.012		
DBH32						-0.062	0.879***	
DBH37						-0.272	0.770**	0.721*

Note: *correlation coefficients are significant for: * – p<0.05, ** – p<0.01, *** – p<0.001*
Source: *compiled by the authors*

The change in the ranks of provenances of Scots pine in terms of trunk diameter occurred with a similar pattern. It is worth noting that at the age of one and five, this indicator was not determined in experimental crops due to the fact that not all trees reached the height (1.3 m) at which this indicator is measured. Therefore, the first order of rank for the average trunk diameter was obtained at the age of 11 years. All subsequent ranking schemes in older cultures differed significantly from it, as evidenced by the corresponding rank correlation coefficients: r_{11-21}= -0.012, r_{11-32} = -0.062, r_{11-37}= -0.272. Rank stabilisation by the average trunk diameter occurred only after 20 years: r_{21-32}=0.879, significant for p<0.001 and r_{21-37}=0.770, significant for p<0.01.

Schemes for ranking Scots pine provenances by the percentage of survival of the number of planted plants and the stock of stem wood, which was formed before the age of 11 years, later changed significantly, as evidenced by low values of correlation coefficients (Table 4). A certain stabilisation of the ranks of provenances in these parameters began to be observed in 21-year-old geographical cultures. A significant change in stock ranks, which was observed in the period 32-37 years, is explained by the consequences of the 2012 snowbreak.

Table 4. *Matrix of Spearman's rank correlation coefficients of the capacity for survival (Surv) and volume of wood stock (VOL) of pine provenances*

Variable	Surv5	Surv11	Surv21	Surv32	Vol11	Vol21	Vol32
Surv11	0.647*						
Surv21	0.377	0.463					
Surv32	0.325	0.409	0.671*				
Surv37	-0.221	-0.091	0.311	0.707*			
Vol21					0.474		
Vol32					0.221	1	
Vol37					-0.080	0.176	-0.012

Note: *correlation coefficients are significant for: * – p<0.05, ** – p<0.01, *** – p<0.001*
Source: *compiled by the authors*

The analysis of indicators of the capacity for survival, growth, and productivity of Scots pine provenances was carried out during the time period of stabilisation of their growth, namely, after geographical crops reached the age of 21 (Table 5). This period of development of pine stands is characterised by increased intraspecific competition for light, water and mineral nutrition elements, and intensive thinning of plantings.

Table 5. *Capacity for survival, growth, and productivity of geographical crops of Scots pine*

No.	Origin (Oblast)	21 years				32 years				37 years			
		Surv, %	H, m	DBH, cm	Vol, m³	Surv, %	H, m	DBH, cm	Vol, m³	Surv, %	H, m	DBH, cm	Vol, m³
1	Volyn	54.0±3.1	9.8±0.27	10.1±0.15	170	48.7±3.1	15.4±0.32	13.7±0.21	297	28.6±2.8	17.6±0.34	16.9±0.26	288
2	Zhytomyr	68.8±2.9	10.2±0.20	10.2±0.14	180	50.8±3.1	15.4±0.33	14.1±0.23	324	34.5±2.9	18.0±0.26	16.7±0.29	308
3	Chernihiv	64.8±2.9	10.9±0.49	10.4±0.16	202	52.1±3.1	16.4±0.31	14.4±0.23	373	36.2±3.0	18.3±0.37	16.9±0.29	422
4	Lviv	70.1±2.8	11.0±0.16	10.2±0.13	197	48.7±3.1	15.8±0.34	14.3±0.23	330	25.0±2.7	19.2±0.38	17.7±0.33	275
5	Cherkasy	64.8±2.9	10.4±0.25	10.8±0.13	176	46.6±3.1	16.3±0.27	14.3±0.22	327	28.0±2.8	18.9±0.34	17.2±0.31	277
6	Kyiv	79.4±2.5	10.3±0.23	9.7±0.14	222	55.7±3.1	15.2±0.33	13.8±0.22	357	32.2±2.9	19.0±0.40	16.9±0.32	348
7	Sumy	65.3±2.9	10.2±0.22	9.9±0.13	172	46.0±3.1	14.3±0.41	13.6±0.22	259	30.7±2.8	17.6±0.44	16.6±0.27	393
8	Luhansk	57.2±3.0	10.0±0.20	9.9±0.16	140	43.9±3.1	14.9±0.22	13.8±0.27	263	30.7±2.8	18.1±0.36	17.0±0.31	317

Source: *compiled by the authors*

Evidently from Table 5, the capacity for survival of provenances decreased the least during this period in the Volyn population (25.4%), and the most in the Kyiv population (47.2%). These figures reflect not only the intensity of natural thinning, but also partly the consequences of snowbreak.

In 37-year-old crops, the capacity for survival of Scots pine provenances from Ukraine ranged from 25% (Lviv provenance) to 36.2% (Chernihiv). At this age, the highest height is characterised by variants from Lviv, Kyiv, Cherkasy, Chernihiv oblasts. The highest intensity of radial growth is distinguished by the same provenances, as well as variants from Volyn and Luhansk. In terms of stem wood reserves, the best is provenance from Chernihiv Oblast, and among the worst – from Volyn and Lviv oblasts.

The growth of non-regional provenances with the local one, there is no population that is significantly better than the local one in terms of average height at the age of 37, but 3 populations (Volyn, Zhytomyr, Sumy) are significantly worse (t=2.10-4.4, $t_{0.05}$=2.06). According to the average trunk diameter, there are also no provenances that grow better than the local one. A two-factor analysis of the growth indicators of Scots pine provenances revealed a statistically significant influence of geographical origin on their growth in height and diameter at the age of 21, 32, and 37 years (Table 6).

Table 6. *Results of dispersion analysis of the growth of Scots pine provenances by height and diameter*

Indicators	Age	Effect	LS	SS	DF	MS	F	p
Height	21	Free term	***	25,875.70	1	25,875.70	15,832.42	0.0001
		Provenance	*	35.44	9	3.94	2.41	0.0126
		Repetition	ns	1.50	1	1.50	0.91	0.3398
		Prov. × Repeat.	ns	13.72	9	1.52	0.93	0.4973
		Error		367.73	225	1.63		
	32	Free term	***	57,103.57	1	57,103.57	25,718.58	0.0001
		Provenance	***	143.36	9	15.93	7.17	0.0001
		Repetition	**	22.59	1	22.59	10.17	0.0016
		Prov. × Repeat.	ns	38.36	9	4.26	1.92	0.0501
		Error		517.34	233	2.22		
	37	Free term	***	101,147.3	1	101,147.3	28,557.27	0.0001
		Provenance	***	158.4	9	17.6	4.97	0.0001
		Repetition	ns	12.5	1	12.5	3.53	0.0613
		Prov. × Repeat.	***	130.2	9	14.5	4.08	0.0001
		Error		1,041.3	294	3.5		
Diameter at a height of 1.3 m	21	Free term	***	346,273.8	1	346,273.8	52,953.91	0.0001
		Provenance	***	635.5	9	70.6	10.80	0.0001
		Repetition	***	225.7	1	225.7	34.52	0.0001
		Prov. × Repeat.	***	332.7	9	37.0	5.65	0.0001
		Error		23,017.8	3,520	6.5		
	32	Free term	***	504,311.3	1	504,311.3	39,127.91	0.0001
		Provenance	***	1,065.1	9	118.3	9.18	0.0001
		Repetition	ns	5.9	1	5.9	0.46	0.4997
		Prov. × Repeat.	***	445.9	9	49.5	3.84	0.0001
		Error		34,632.2	2,687	12.9		
	37	Free term	***	459,022.5	1	459,022.5	34,505.09	0.0001
		Provenance	***	1,023.1	9	113.7	8.55	0.0001
		Repetition	***	399.6	1	399.6	30.04	0.0001
		Prov. × Repeat.	***	450.5	9	50.1	3.76	0.0001
		Error		22,375.7	1,682	13.3		

Note: *SS – sum of squares; LS – level of significance: ***$p<0.001$, **$p<0.01$, *$p<0.05$; ns –not significant; DF – degrees of freedom; MS – mean square; F – value of F-statistics; p – significance level*

Source: *compiled by the authors*

Correlation and regression analyses were performed to assess the impact of indicators that characterise the place of seed harvesting on the growth and stability of Scots pine provenances. As can be seen from the Table 7, at the age of 21, the calculated paired correlation coefficients were statistically insignificant. Later, at the age of 32 and 37 years, there is a direct positive relationship between the geographical latitude of the seed origin and the capacity for survival of provenances in geographical crops (Pearson correlation coefficients r=0.695 and 0.675 are significant for $p<0.05$). The relationship between the growth indicators of provenance (height and diameter of the trunk) and the geographical coordinates of the seed source is described by negative values of correlation coefficients (both significant and insignificant), that is, the best growth of the offspring of southern and western provenances is distinguished. At the same time, these growth rates at an older age (32 and 37 years) directly correlate with the average annual temperature and duration of the growing season, and the capacity for survival of provenances is inversely correlated.

Table 7. *Pearson correlation coefficients between capacity for survival (Surv), height (H), trunk diameter (DBH), and geographical coordinates (N, E), average annual air temperature (AAT), and growing season duration (GS)*

Age / Indicators	21			32			37		
	Capacity for survival (Surv.)	Height (H)	Diameter (DBH)	Capacity for survival (Surv.)	Height (H)	Diameter (DBH)	Capacity for survival (Surv.)	Height (H)	Diameter (DBH)
N	0.299	-0.049	-0.329	0.695**	-0.157	-0.438	0.675**	-0.591*	-0.611*
E	-0.115	-0.254	-0.240	-0.123	-0.328	-0.276	0.347	-0.209	-0.369
AAT	-0.333	-0.016	0.443	-0.572*	0.302	0.483	-0.696**	0.505	0.669**
GS	-0.375	-0.001	0.343	-0.475	0.377	0.465	-0.699**	0.564*	0.675**

Note: *Significance level: ***p<0.01, **p<0.05, *p<0.1*
Source: *compiled by the authors*

The statistical significance of paired correlation coefficients between the indicators of the capacity for survival and growth of provenances and the geographical latitude of the location of mother plantings, the average annual air temperature and the duration of the growing season at the seed harvesting point prompted regression analysis, which resulted in a number of adequate one-factor linear models (Table 8).

Table 8. *Mathematical models for estimating the capacity for survival and diameter at breast height of Scots pine provenances*

Model number	Analytical form of the model (model adequacy criteria)
1	Surv32 = -138.4 + 3.7N (R^2=0.483, F=7.48, p<0.026)
2	Surv37 = -99.9 + 2.6N (R^2=0.456, F=6.71, p<0.032)
3	Surv37 = 68.8 - 4.6AAT (R^2=0.484, F=7.52, p<0.025)
4	DBH37 = 10.8 + 0.7AAT (R^2=0.448, F=6.49, p<0.034)
5	Surv37 = 154.5 – 0.6GS (R^2=0.488, F=7.63, p<0.025)
6	DBH37 = -2.9 + 0.1GS (R^2=0.455, F=6.69, p<0.032)

Note: $F_{table\ 0.05}(1.8) = 5.32$
Source: *compiled by the authors*

The obtained mathematical models, in particular signs and values of regression coefficients in them, indicate that in 32-year-old geographical crops of Scots pine, an increase in the latitude of the place of harvesting Scots pine seeds by one degree caused an increase in the capacity for survival of provenance by 3.7%, and in 37-year-olds – by 2.6%. The capacity for survival of offspring of populations at 37 years of age decreased by 4.6%, if the average annual air temperature of the location of the mother plant increased by 1 about C, and by 0.6% – when the duration of the growing season in the region of seed harvesting increased by 1 day. The obtained adequate regression models, in which the regressant is the average diameter of the trunk of provenances, and the regressor is the geographical latitude of the seed source, allow asserting with some caution about the manifestation of clinal variability of the trunk diameter at breast height in the studied part of its range in Scots pine. In addition, Table 8 shows that an increase in the average annual air temperature in the seed source by 1°C caused an increase in the average trunk diameter of 37-year-old provinces by 0.7 cm, and the extension of the growing season by 1 day caused an increase in this indicator by only 0.1 cm.

The scientific debate about the age at which final conclusions can be drawn about the stabilisation of provenances ranks has been going on for a long time. König (2005) suggests that it is advisable to observe geographical cultures from at least one-third to one-half of the age of logging turnover. Our research supports the view that early diagnosis (up to 10 years) of population growth does not always guarantee reliable final conclusions. Similar to the results of a study of geographical beech crops conducted by Kleinschmit and Svolba (1995), the data obtained (Table 3) indicate the presence of a significant (although statistically insignificant) correlation between the ranks of provenances by height in the age range of 5 and 11 years and a weak one in the intervals of 5-21, 5-32, 5-37 years. The order of ranks of provenances, which was in 11-year geographical cultures, was not preserved later, as evidenced by low (even negative) rank correlation coefficients for pairs of 11-21, t11-32, and 11-37 years. Therefore, to answer the question of the optimal age for early and final diagnosis of provenance growth, it is necessary to continue studying geographical cultures, which are also created according to the "long-term" design.

The populations that are represented in the studied geographical cultures represent the southern part of the Scots pine range, both continuous and disjunctive (marginal). This territory extends from North to South for 500 km, from West to East – for 1,100 km. Many provenances from this part of the pine range have been tested for a long time in a number of other geographical crops. Tereshchenko *et al*. (2008), who conducted the most recent studies of these crops, found that at the age of 90, the highest productivity was characterised by local (Sumy) pine. According to the study, Sumy provenance in terms of volume of stem wood reserve (393 $m^{3}*ha^{-1}$) is one of the best in the conditions of the Kyiv Polissia.

Since 1972, for 20 years in the Kharkiv and Donetsk oblasts near the southern border of the Left-Bank Forest-Steppe, a number of geographical crops have been established, where 169 provenances of Scots pine from almost all parts of its range on the territory of the former Soviet Union are tested. As a result of many years of research by Zhurova (2007), 11 provenances were recommended for use as seed sources, among which three (Cherkasy, Sumy, Kyiv) are similar in origin to those tested in crops near Kyiv.

In 1974-1976, under the methodological guidance of A.M. Shutyaev, a large-scale project was implemented to test 113 provenances of Scots pine in 33 locations in the former Soviet Union. According to the results of studies by Shutyaev and Giertych (2000) of the growth dynamics of 5-20-year-old offspring of populations, the range of pine is divided into 9 parts, one of which (Western Continetntal) covers the region of provenances, which are also tested in crops in 1981 near Kyiv. And again, Ukrainian ancestry is characterised by outstanding growth in height in most European locations.

The range of intraspecific variability of Scots pine, which is found in geographical cultures, depends on the breadth of their coverage of the species' range. Barzdajn *et al*. (2016), investigating one of the five geographical Scots pine crops of the IUFRO experimental programme, which presents 20 provenances from all over Europe (amplitude 40°-60°N, 4°-33°E), found significant differentiation of populations in all indicators of growth and capacity for survival. In particular, in terms of wood reserves, the variation reached 92%. Given the relatively small proportion of the pine range represented by provenances in geographical cultures, a significant change in growth rates should not be expected. Evidently from Table 5, at the age of 32 and 37 years, the range of fluctuations in average heights was 2.2-2.4 m (CV=4.9% and 4.0%), and average trunk diameters – 2.0-2.6 cm (CV=4.6% and 4.5%). At the same time, the variation in productivity due to a significant variation in capacity for survival was more noticeable (CV=15.7% and 11.6%).

One of the important theoretical and applied tasks of genecological research is to identify the nature of variability in adaptive and quantitative characteristics of a forest tree species. Starting from the paper by Langleta (1959), which has already become a classic and which proved the existence of an almost functional relationship between the length of the day and the dry matter content in the needles of Scots pine seedlings of various geographical origin, later studies of geographical cultures of many species of woody plants revealed clinal variation along the geographical (ecological) gradients of other features: Cunningham and Haverbeke (1991) – winter colour of needles, Oleksyn *et al*. (1998) – duration of the shoot growth period, Zhelev and Lust (1999) – intensity of growth by diameter, Andersen and Fedorkov (2004) – frost resistance.

In some parts of the range of Scots pine, clinal variation of adaptive features is observed. Hall *et al*. (2021) found such a model of variability for frost resistance in the latitudinal and longitude directions. The constructed significant regression models allow making assumptions about the possible clinal nature of the variation in the percentage of survivability of provenances and the average trunk diameter at breast height. At the same time, the variability of the average height of provenances is not characterised by clinality in experimental cultures. The reason for this is that some of the populations presented here are marginal at the southern border of the Scots pine range, the gene flow between which is limited due to spatial remoteness.

CONCLUSIONS

Long-term (for more than 25 years) studies of Scots pine provenances in geographical cultures near Kyiv have shown that early (at the age of 11 years) diagnosis of the capacity for survival, growth, and productivity of Scots pine provenances is uninformative. Stabilisation of the ranks of provenances in these indicators is observed only after 21 years. A more reliable assessment of the growth and condition of the offspring of Scots pine populations in geographical cultures can be obtained at an age that corresponds to a third to half of the age of the main felling.

Despite the relatively low variation in the indicators of the average height, average trunk diameter, and volume of stem wood stock of Scots pine provenances, the effect of influencing them by the geographical origin of seeds is statistically significant.

The trend of clinal variability in the survival of provenances and the average diameter of their trunks along the geographical (latitudinal) and ecological (temperature) gradients is revealed. The marginality of Scots pine populations at the southern border of its range, which is accompanied by a low intensity of gene flows, obviously limits the manifestation of a clear model of clinal variation of traits in their offspring in geographical cultures.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Andersson Gull B., Persson, T., Fedorkov, A., & Mullin, T.J. (2018). Longitudinal differences in Scots pine shoot elongation. *Silva Fennica,* 52(5), article number 10040. doi: 10.14214/sf.10040.

[2] Andersson, B., & Fedorkov, A. (2004). Longitudinal differences in Scots pine frost hardiness. *Silvae Genetica*, 53(1-6), 76-80. doi: 10.1515/sg-2004-0014.

[3] Ballian, D., & Šito, S. (2017). Analysis of differences of growth and phenology of provenances of Scots pine (*Pinus sylvestris*) in provenance experiment at Žepče. *Biosystems Diversity,* 25(3), 228-235. doi: 10.15421/011735.

[4] Barzdajn, W., Kowalkowski, W., & Chmura, D.J. (2016). Variation in growth and survival among European provenances of *Pinus sylvestris* in a 30-year-old experiment. *Dendrobiology*, 75, 67-77. doi: 10.12657/denbio.075.007.

[5] Buksha, I.F., Bondaruk, M.A., Tselyshchev, O.G., Pyvovar, T.S., Buksha, M.I., & Pasternak, V.P. (2017). Vitality forecasting for Scots Pine and English Oak in condition of climate change in the lowland of Ukraine. *Forestry and Forest Melioration*, 130, 146-158.

[6] Chmura, D.J., Guzicka, M., & Rożkowski, R. (2021). Accumulation of standing aboveground biomass carbon in Scots pine and Norway spruce stands affected by genetic variation. *Forest Ecology and Management*, 496, article number 119476. doi: 10.1016/j.foreco.2021.119476.

[7] Cunningham, R.A., & Van Haverbeke, D.F. (1991). *Twenty-two year results of a Scots pine (Pinus sylvestris L.) provenance test in North Dakota.* Fort Collins: US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

[8] Gülcü, S., & Bilir, N. (2017). Growth and survival variation among scots pine (*Pinus sylvestris* L.) provenances. *International Journal of Genomics*, 2017, article number 1904623. doi: 10.1155/2017/1904623.

[9] Hall, D., Olsson, J., Zhao, W., Kroon, J., Wennström, U., & Wang, X.R. (2021). Divergent patterns between phenotypic and genetic variation in Scots pine. *Plant Communications*, 2(1), article number 100139. doi: 10.1016/j.xplc.2020.100139.

[10] Kivimäenpää, M., Markkanen, J-M., Ghimire, R.P., Holopainen, T., Vuorinen, M., and & Holopainen, J.K. (2018). Scots pine provenance affects the emission rate and chemical composition of volatile organic compounds of forest floor. *Canadian Journal of Forest Research.* 48(11), 1373-1381. doi: 10.1139/cjfr-2018-0049.

[11] Kleinschmit, J., & Svolba, J. (1995). Results of the Krahl-Urban beech (*Fagus sylvatica* L.) provenance experiments 1951, 1954 and 1959 in northern Germany. In *Genetics and Silviculture of Beech. Proc. from the 5th beech Symposium of the IUFRO P.G. P1.10-00*. Hørsholm: Danish Forest and Landscape Reseach Institute.

[12] König, A.O. (2005). Provenance research: Evaluating the spatial pattern of genetic variation. In T. Geburek, J. Turok (Eds.) *Conservation and Management of Forest Genetic Resources in Europe* (pp. 275-333). Zvolen: Arbora Publischer.

[13] Langlet, O. (1959). A cline or not a cline, a question of Scots pine. *Silvae Genetica*, 8, 13-22.

[14] Matisons, R., Schneck, V., Jansone, D., Bāders, E., Dubra, S., Zeltiņš, P., & Jansons, Ā. (2021). South-Eastern baltic provenances of scots pine show heritable weather-growth relationships. *Forests,* 12(8), article number 1101. doi: 10.3390/f12081101.

[15] Memišević Hodžić, M., Bejtić, S., & Ballian, D. (2020). Interaction between the effects of provenance genetic structure and habitat conditions on growth of scots pine in international provenance tests in Bosnia and Herzegovina. *South-East European Forestry*, 11(1), 11-16. doi: 10.15177/seefor.20-03.

[16] Notivol, E., Santos-del-Blanco, L., Chambel, R., Climent, J., & Alía, R. (2020). Seed sourcing strategies considering climate change forecasts: A practical test in scots pine. *Forests*, 11(11), article number 1222. doi: 10.3390/f11111222.

[17] Oleksyn, J., Tjoelker, M.G., & Reich, P.B. (1998). Adaptation to changing environment in Scots pine populations across a latitudinal gradient. *Silva Fennica*, 32(2), 129-140. doi: 10.14214/sf.691.

[18] Shutyaev, A.M., & Giertych, M. (2000). Genetic subdivisions of the range of Scots pine (*Pinus sylvestris* L.) based on a transcontinental provenance experiment. *Silvae Genetica*, 49(3), 137-151
[19] Szaban, J., Jelonek, T., Okińczyc, A., & Kowalkowski, W. (2023). Results of a 57-year-long research on variability of wood density of the scots pine (*Pinus sylvestris* L.) from different provenances in Poland. *Forests,* 14(3), article number 480. doi: 10.3390/f14030480.
[20] Taeger, S., Zang, C., Liesebach, M., Schneck, V., & Menzel, A. (2013). Impact of climate and drought events on the growth of Scots pine (*Pinus sylvestris* L.) provenances. *Forest Ecology and Management,* 307, 30-42. doi: 10.1016/j.foreco.2013.06.053.
[21] Tereschchenko, L.I., Samodai, V.P., & Moroz, V.V. (2008). *The current state and prospects of V.D. Ogievsky provenance trials and other breeding objects of Scots pine in the Sobitsky forestry of SE "Shostkinske FE" in the Sumy region.* Kharkiv: URIFFM.
[22] Zhelev, P., & Lust, N. (1999). Provenance study of Scots pine (*Pinus Sylvestris* l.) in Belgium. 1. Evaluation of phenoptypical traits. *Silva Gandavensis,* 64, 24-36. doi: 10.21825/sg.v64i0.826.
[23] Zhurova, P.T. (2007). The results of 25-year testing of Scots pine climatypes in the pine forests at the steppe bounder in the Ukraine. In *Forest typology in Ukraine: Current state, prospects for development. Proceedings of 11th Pogrebnyak Readings* (pp. 124-126). Kharkiv: URIFFM.

Географічні культури *Pinus sylvestris* L.: оцінка у віці половини ротаційного періоду

Ярослав Дмитрович Фучило
Доктор сільськогосподарських наук, професор
Малинський фаховий коледж
11645, вул. М. Маклая, 1, с. Гамарня, Україна
Інститут біоенергетичних культур і цукрових буряків НААН
03141, вул. Клінічна, 25, м. Київ, Україна
https://orcid.org/0000-0002-2669-5176

Юрій Іванович Гайда
Доктор сільськогосподарських наук, професор
Відокремлений підрозділ Національного університету біоресурсів і природокористування України
«Бережанський агротехнічний інститут»
47500, вул. Академічна, 20, м. Бережани, Україна
Національний університет «Чернігівська політехніка»
14027, вул. Шевченка, 85, м. Чернігів, Україна
https://orcid.org/0000-0001-6019-9654

Ігор Дмитрович Іванюк
Доктор сільськогосподарських наук, професор
Малинський фаховий коледж
11645, вул. М. Маклая, 1, с. Гамарня, Україна
https://orcid.org/0000-0002-4969-8783

Ольга Степанівна Мажула
Кандидат сільськогосподарських наук
Інститут біоенергетичних культур і цукрових буряків НААН
03141, вул. Клінічна, 25, м. Київ, Україна
https://orcid.org/0000-0002-0241-5280

Тетяна Миколаївна Іванюк
Кандидат сільськогосподарських наук, доцент
Поліський національний університет
10008, б-р Старий, 7, м. Житомир, Україна
https://orcid.org/0000-0001-6171-4064

Анотація. Дослідження географічних культур є актуальним з огляду на те, що вони є одним із надійних інструментів виявлення можливих сценаріїв реакції видів лісових деревних рослин на зміну клімату. Метою досліджень створених у 1981 році географічних культур сосни звичайної у Київській області була порівняльна оцінка росту і продуктивності провенієнцій у різні вікові періоди, визначення оптимального часу ранньої та кінцевої діагностики їх ранжування та моделювання взаємозв'язку показників росту і збереженості провенієнцій з кліматичними та іншими середовищними змінними у віці 21, 32 та 37 років. Методом ANOVA встановлено статистично значущий вплив географічного походження насіння на ріст географічних культур. У 37-річному віці збереженість варіює від 25 % (Львівська провенієнція) до 36,2 % (Чернігівська провенієнція). У цьому віці найбільшою висотою характеризуються популяції із Львівської, Київської, Черкаської областей. За інтенсивністю радіального приросту виділяються ці ж самі провенієнції, а також варіанти з Волині і Луганська. За запасом стовбурової деревини найкращою є провенієнція з Чернігівської області. Стабілізація рангів провенієнцій за показниками збереженості, росту і продуктивності спостерігається лише після 21 року. Зроблено припущення, що найбільш точну оцінку росту і стану провенієнцій сосни звичайної можна отримати у віці, який відповідає третині-половині віку головної рубки. Виявлено тренд клінальної мінливості збереженості провенієнцій і середнього діаметра їх стовбурів вздовж географічного (широтного) та екологічного (температурного) градієнтів. Результати досліджень можуть бути використані при актуалізації діючого лісонасіннєвого районування України

Ключові слова: географічна мінливість; показники росту; збереженість; рангова кореляція; клінальна мінливість