Breeding effect of selection methods (population, seed, and single-plant) at seed sites of various genetic levels in the Volgograd region

S.N. Kryuchkov, *A.V.* Solonkin, *A.S.* Solomentseva, *S.A.* Egorov*, and *D.A.* Gorbushova

FSBSI "Federal Scientific Center of Agroecology, Integrated Land Reclamation, and Protective Afforestation of the Russian Academy of Sciences", city of Volgograd, Russia

Abstract. The article presents methods and results of selection of breeding material of Crimean pine (*Pinus nigra subsp. pallasiana* (Lamb.)., resistant to various stress factors. The original and promising cultivars for further use in breeding, introduction, competitive and production tests have been identified. With the help of hierarchical variance analysis, it was established that old-age plantings are a source of useful breeding traits and material for further breeding and genetic work.

1 Introduction

The structure of existing plantings in arid regions, their composition, productivity, protective functions, aesthetic and sanitary-hygienic properties are largely determined by the set of measures that need to be implemented to maintain their condition. Data from long-term surveys have shown that anthropogenic activity has led to a sharp reduction in the area of forest plantations and a significant deterioration in the quality of existing plantings [3, 4, 5, 14]. It is also established that the main cause of the death of forest crops is severe weather conditions – dry winds and frosts. Prolonged dry winds in the spring have a detrimental effect on the flowering of tree species, in the summer they cause the leaves to dry out, as a result of which early leaf fall can be observed [1, 2, 6].

The correct choice of variability carriers and the setting of specific selection goals is an important condition for artificial selection for subsequent reproduction and breeding. Old-age plantings have been tested for a long time by selection, they must be preserved as an assortment of screen plantings and to identify useful traits for fixing them in subsequent generations by re-crossing [7, 8, 9, 10, 11, 12, 13, 15].

The object of research was a species of Crimean pine – *Pinus nigra subsp. pallasiana* (Lamb.). This is a tree not demanding to soil conditions, fast-growing, used in field-protecting, sand-strengthening, and landscaping plantings.

Two approaches were used in the creation of seed plantations (SP): clone and population. Therefore, the vegetative and seed progeny of 23 plus trees selected in 50-70 summer pine plantations of the Volgograd region are presented at the SP of the

* Corresponding author: alexis2425@mail.ru

Novoanninsky SSC. Clone, family, and population pine plantations represent the first generation of trees selected before checking them by progeny (Figure 1).

Fig. 1. Selection and seed-growing complex of pine trees in the Novoanninsky forestry (clone, family, and population plantations), age 25 years, area 75 hectares.

2 Materials and Methods

A promising direction to increase their genetic level and efficiency is the reconstruction of plantations by removing clones or families that have not passed progeny test.

To create second-generation plantations, biotypes were selected which progeny was resistant to the main limiting factors: droughts, pests, diseases, while maintaining good growth and condition.

The number of trees with progeny significantly exceeding the control is usually small, especially in the arid zone, that is why, it is possible to attract a gene pool of tree species from other areas that have shown better results in growth and preservation.

According to the recommendations of P. I. Molotkov, plantations of an increased genetic level can be created by selecting the best trees in test crops of primary selection. Family-clone plantations are also offered, which are created by selecting the best trees in the families of test crops and their further vegetative reproduction.

Finally, the most promising for protective afforestation is the creation of varieties-populations that combine genetic diversity with selection in quality and productivity.

Improvement is the breeding differential x heritability, where the breeding differential is the difference between the selected and average parents.

At the same time, depending on the breeding direction, mass or family selection is carried out, progeny is tested in experiments with sibs, half-sibs, clones.

To study the selection effectiveness, measurements of height, trunk diameter, crown diameter were carried out, the yield of cones on clone, family, and population pine plantations was estimated.

When assessing heritability, variability, and genetic improvement, D. Wright variance analysis was used. Its peculiarity is the hierarchical subordination of structural components, when a group of relatively low position is dependent on groups of higher rank associated with it. To determine the effect of the reliability of the factors, F_{fact} was calculated and compared with F_{05} and F_{01} (Table 1).

Table 1. Hierarchical variance analysis of clone height variability.

Variations	Degrees of variance	Sum of squares	Mean square	Variance ratio		
				$F_{fact.}$	F_{05}	F_{01}
Between plantings fact. A	4	79	19.75	7.6	2.4	3.4
Between trees fact. B	2	57	2.59	19.2	1.6	1.9
Residual variations	225	29	0.13			
Total	246	165				

$N=11590$ $D_y = 165$ $D_x = 136$ $D_z = 29$ $D_A = 79$ $D_B = 57$

$S^2_A = \frac{17,16}{(vp)} = 0,38$ $S^2_B = \frac{2,46}{5} = 0,49$ $S^2_y = 0,39+0,43+0,13 = 1,0$

$h^2_A = \frac{0,38}{1} = 0,38$ $h^2_B = \frac{0,49}{1} = 0,49$ $h^2_z = 0,13$

The evaluation of the selection effectiveness and heritability of the selected traits was carried out in the seed-growing complex of Novoanninskaya pine, which includes a 25-year-old clone plantation from the progeny of 28 plus trees, a population plantation from the progeny of 4 best populations, and a family plantation from the progeny of 13 plus trees.

3 Results and Discussion

To evaluate the mother plantations by the success of clonal progeny growth, to determine the strength of the effect of various factors on the productive trait, the A-effect on the productive trait of the plantation was analyzed in which the mother plantations were selected. B-effect of mother plantations and the effect of random factors. The effect of the C-ecological factor has not changed, since the placement of clones on the plantation according to a randomized scheme allows reducing the effect of this factor in the experiment to a minimum. As can be seen from the analysis results, the null hypothesis is refuted at the levels of A and B factors. Consequently, the growth of clones, and hence other genetic traits, is significantly influenced by the planting and plus tree factors, but the differences are relatively small.

The calculation of factorial variances allowed to determine the strength of the effect of the studied factors: the share of the plantings effect is 38%, the mother plantation effect is 49%, and the share of random traits accounts for 13%.

The effect on the fruiting of plantation and mother plantation in which the trees were selected was studied by constructing a nested variance complex with factors A-plantation effect and B-plus tree (Table 2).

Table 2. Nested variance analysis of variability of clones fruiting.

Variations	Degrees of variance	Sum of squares	Mean square	Variance ratio F_f	F_{st} 5 %	F_{st} 1 %
According to fact A	4	0.8	0.2	0.24	2.4	3.4
According to fact B	22	18	0.82	2.05	1.6	1.9
Residual	225	90	0.40			
Total	246	109				

Fruiting clones:

$N = 1159$ $D_y = 109$ $D_x = 19$ $D_z = 90$ $D_A = 0,8$ $D_B = 18$

$(v_n)_o = \frac{1}{5-1}\left(247-\frac{17237}{247}\right) = 44.3$ $(n_A)_o = \frac{1}{4}(10+8.97+8.88+9.29+10)-(9.2)=2.58$

$(n_B)_o = \frac{1}{28-1}(247-47,1) = 7,4$ $n_o = \frac{2.58+7.4}{2} = 4.99$

$S_B = \frac{S^2 - S^2_z}{5} = 0.08$ $S^2_y = 0.49$

$h^2_A = \frac{0.013}{0,49} = 0.02$ – plantings $h^2_B = \frac{0.08}{0,49} = 0.16$ – mother plantings

$h^2_z = \frac{0.40}{0.49} = 0.82$ – random factors

As can be seen from Table 2, the effect of the planting factor on the clonal progeny fruiting turned out to be unreliable.

The mother planting effect was significant at 1% and 5% levels of significance only in relation to the plus tree factor. The calculation of factorial variances allowed to conclude that the effect of planting is only 2%, the effect of the plus tree is 16%, and the share of random, unaccounted factors accounts for 82%.

The general condition of the tree and its fruiting on the plantation is largely determined by the crown development. The indicator that most fully reflects the crown development is the crown area. In the nested dispersion complex, the effect of the same factors A – planting, B – mother tree and random stochastic factors was analyzed (Table 3, 4).

According to the results of the analysis, the null hypothesis is refuted at the level of factor B, the mother planting factor significantly affects the variability of the crown area of vegetative progeny.

$N = 165830$ $D_y = 2866$ $D_x = 2263$ $D_z = 603$ $D_A = 203$ $D_B = 2060$

$S^2_A = \frac{42,9}{44,3} = 0,97$ $S^2_B = 18,2$ $S^2_y = 0,97+18,2+2,68 = 21,8$

$h^2_A = 0{,}56 \qquad h^2_B = 21{,}3 \qquad h^2_z = 0{,}13$

Table 3. Nested variance analysis of the effect of different factors on the crown area.

Variations	Degrees of variance	Sum of squares	Mean square	Variance ratio		
				$F_{fact.}$	Fst 5 %	1 %
Between plantings fact. A	4	203	50.7	0.54	2.4	3.4
Between trees fact. B	22	2060	93.6	34.7	1.6	1.9
Residual variations	225	603	2.68			
Total	246	2866				

The calculation of factorial variances allowed to calculate the strength of the trait effect. According to this calculation, the crown area is 83% due to the effect of the mother planting, 5% - of the planting, and 12% to the effect of random stochastic factors.

To evaluate the mother plantings by the success of the seed progeny growth from free pollination (half-sibs), nested dispersion complex was also formed, in which the effect of factors A – planting, B – mother planting or plus tree, as well as random stochastic factors on the growth energy, were analyzed. Growth is taken for analysis as a sign in which the adaptability of this genotype to environmental conditions and the realization of genetic properties through growth energy is manifested.

Table 4. Nested variance analysis of height variability in half-sibs on a pine plantation.

Variations	Degrees of variance	Sum of squares	Mean square	Variance ratio		
				$F_{fact.}$	F_{05}	F_{01}
Between plantings fact. A	4	1030	275.5	2.25	2.4	3.5
Between trees fact. B	9	1028	114	475	2.0	2.6
Residual variations	116	28	0.24			
Total	129	30				

$N = 5071 \qquad D_y = 30 \qquad D_x = 2 \qquad D_z = 28 \qquad D_A = 1030 \qquad D_B = 1028$

$(v_n)_o = \frac{1}{5-1}(130-48.2) = 20.5 \qquad (n_A)_o = \frac{1}{4}(109.57+9.33+10+10) = 2.7$

$(n_B)_o = \frac{1}{14-1}(130-48.9) = 6.24 \qquad n_o = \frac{2.7+6.24}{2} = 4.45$

$S^2_A = \frac{S^2_1 - S^2_z}{(v\,n)_o} = 6{,}9 \qquad S^2_B = \frac{S^2_2 - S^2_z}{n} = 25.5 \qquad S^2_y = 6.9+25.5+0.24 = 32.6$

$h^2_A = 0.21 \qquad h^2_B = 0.78 \qquad h^2_z = 0.01$

As can be seen from Table 4, the null hypothesis is refuted at both levels with respect to factor B, thus the mother plantings significantly affect the height growth of their seed progeny from free pollination.

The calculation of factorial variances showed that the reliable effect of mother plantings is 78%, 21% is an unreliable effect of planting, and only 1% is due to random factors.

Thus, the growth of clones and the growth of families depends on the specific mother planting. Therefore, clonal progeny does not have significant advantages on this basis.

According to the same principle, the effect of factors A – plantings, B – mother tree on the yield of half-sibs on the seed plantation was analyzed, the effect of environmental factors was random (Table 5).

Table 5. Variance analysis of fruiting variability of families on pine SP.

Variations	Degrees of variance	Sum of squares	Mean square	Variance ratio		
				$F_{fact.}$	F_{05}	F_{01}
Between plantings fact. A	4	4.3	1.01	0.26	2.4	3.5
Between trees fact. B	9	4472	497	60.6	2.0	2.6
Residual variations	116	58	0.5			
Total	129					

$N=904 \quad D_y=95 \quad D_x=37 \quad D_z=58 \quad D_A=4{,}3 \quad D_B=33.9$

$S^2_A = \underline{S^2_1 - S^2_z} = 0.13 \qquad S^2_B = \underline{S^2_2 - S^2_z} = 0.73$

$(v\ n)_o$

$S^2_y = 0.13+0.73+0.5=1.36$

$h^2_A=0.09 \qquad h^2_B = 0.53 \qquad h^2_z = 0.36$

In Table 5, the null hypothesis is refuted at 1% and 5% levels with respect to factor B, the yield of half-sibs is significantly affected by the mother planting factor. The calculation of factorial variances allowed to calculate that the effect of mother plantings on fruiting is 53%, the share of random factors accounts for 36%. To select promising families and clones for second-generation plantations, data on growth, fruiting, and seed plantations of the Novoanninsky seed complex were ranked. The correlation of ranks in height between clones and families was $r_s = 0.65$ between diameters 0.43, the relationship is quite close.

Correlations in crown area between clones and families $r_s = 0.053$, that is, there is practically no relationship; there is a negative relationship in fruiting $r_s = 0.41$, that is, the better the clones bear fruit, the weaker the families and vice versa. It has been established that the greatest breeding effect is achieved by the growth of half-sibs. The change in ranks is 130-164%, selection by growth of clones also gives an effect of 130-164% (Table 6).

Table 6. Comparative effectiveness of different pine selection methods on the seed plantations of the Novoanninsky forestry.

Indicators	Intensity of selection	Relative efficiency of selection to the average rank by variant			
		Selection by growth of half-sibs	Selection by yield capacity	Selection by growth of clones	Selection by complex
Mean yield of seeds from a single clone tree	20	114	129	101	121
	40	118	164	90	129
Average height of seed progeny	20	130	113	110	128
	40	164	121	104	145
Average height of vegetative progeny	20	105	102	130	108
	40	106	92	164	128

Nevertheless, the greatest breeding and economic effect is given by selection according to trait complex. According to the results of the economic calculation carried out by NIILGiS, the conditional annual economic effect when selected for two traits is three times higher than the control variant and two times higher than when selected for one of the trait.

In our case, with an increase in the selection intensity from 20 to 40%, its effectiveness increases significantly. When selecting by the growth of seed progeny, the excess of yield control is achieved, when selecting by the growth of clones, the yield does not exceed the average rank.

For the purpose of promising mother plantings for the growth, development, fruiting of their family and vegetative progeny, data on growth, fruiting, clone area were analyzed according to the method proposed by Yu. E. Bulygin. According to Table 7, 5 clones are classified as promising, of which 3 are representatives of the Novoanninsky population, 6 are unpromising, and the rest occupy an intermediate position.

Table 7. Selection of promising pine clones based on the results of their evaluation on seed plantations in Novoanninsky SSC.

Clone name*	Integral evaluation	Rank by integral evaluation
Promising		
V-12	0.96	1
K-2A	0.90	2
K-256	0.90	3
V-8	0.90	4
K-2	0.89	5
Medium		
V-7	0.89	6
K-39	0.89	7
K-63	0.88	8
A-2	0.88	9
V-11	0.87	10
R-51	0.87	11
K-65	0.87	12
R-24	0.86	13
D-4	0.86	14
V-10	0.86	15
V-65	0.85	16
K-1	0.84	17
V-6	0.84	18
D-10	0.84	19
R-25	0.84	20
R-44	0.84	21
Unpromising		
V-14	0.83	22
K-4	0.82	23
R-5	0.83	24
K-828	0.79	25
K-691	0.75	26
R-10	0.73	27

*Note: K – Kamyshinskaya, R – Rudnyanskaya, V – Archedinskaya, D – Danilovskaya

As can be seen from Table 7, three clones are classified as promising, all representatives of the Kamyshinskaya population, 4 are unpromising and the rest are medium promising.

The height and diameter of the Crimean pine crown for combined plus families and populations have similar indicators at different ages, since they are grown against a common ecological background, the absence of a significant difference confirms the equality of phenotypic variances according to the studied characteristics (Table 8).

Table 8. Analysis of genetic and ecological variability of annual increments of the family SP of Crimean pine of the Novoanninsky forestry.

Family number	Variance			N^2 (coefficient of inheritance in a broad sense)
	genetic	paratypic	phenotypic	
1	3.7	4.1	7.8	0.48
2	4.8	2.5	3.4	0.65
3	3.4	7.2	10.6	0.32
4	2.4	3.4	5.9	0.42
5	3.5	3.6	7.1	0.49
6	3.0	2.5	5.5	0.54
7	2.8	3.9	6.8	0.42
8	2.0	4.3	6.3	0.32
9	3.8	6.7	10.5	0.36
10	3.2	4.9	8.1	0.39
11	2.0	2.6	4.6	0.43
12	4.4	12.7	17.1	0.26
13	3.9	1.4	5.3	0.73
14	3.8	7.0	10.8	0.35

4 Conclusions

In addition to breeding selection, to fully utilize the reclamation role of established and existing forest seed plantations, it is recommended to pay great attention to planning, designing, as well as significantly improving the quality of work on growing new plantings and caring for them, including various types of pruning, clean cutting, soil care in rows and row spacing of forest strips, pest and disease control in forest plantations, care for young plantings. Forest offence with trees and shrubs should not be allowed in screen forest plantations, including cattle grazing and driving, driving cars, and making fire. Old-age plantings should be corrected by plowing of empty rows, followed by harrowing and cultivation, planting 2-3-year-old seedlings of fast-growing species and shrubs, carrying out measures to care for the soil until the crown contacts.

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