Survival rate of the Crimean pine forest cultures (*Pinus pallasiana* D. Don) created by non-standard seedlings on Don hilly sands

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Abstract. Experimental forest cultivations of Crimean pine were produced on cohesive-sandy soils with hilly terrain to show the possibility of using non-standard seedlings. The minimum height of the seedlings was 10 cm (a standard indicator) compared to 2.0…2.9 cm – the stem diameter at the root collar (a non-standard indicator). In an experiment the agronomic technique of preplant treatment of the seedlings’ root systems with a solution of Kornevin (a biostimulant, Agrosintez, Russia) was used. When creating forest cultures by hand planting, the differences between the experimental options in terms of the survival rate and the nature of variation depending on the quality of the seedlings used were not significant (actual Student's and Fisher's coefficients is less than tabular). Treatment of root systems with Kornevin solution contributed to a more even distribution of the plants in the area. Mechanized planting did not provide for a high survival rate of forest cultures (the rate was 58.4% in the 1st year and 37.3% in the 3rd year), while the surviving plants did not form a homogeneous population (variation factor 30.5…71.0). The results indicated that it was possible to use seedlings of non-standard sizes in renewal after treating root systems with solutions of root stimulants.

1. Introduction

Due to the topographic features, granulometric composition, and low soil fertility, hilly sand is rightfully considered the most difficult soil type for tree plantation [1-3]. In the basin of the Central Don (Russia), the largest massifs (by area) are located in the north of the Rostov region (Kazan-Veshensky sand massif) and in the west of the Volgograd region (Archedinsky-Don sand massif) [1, 3]. Annually in the forestry areas confined to them, forest cultures are created on an area of 150-200 ha each [4, 5].

The effectiveness of reforestation is due to the joint manifestation of many factors. One of them is the use of planting material that meets regulatory requirements for age and biometric indicators [6]. In the last 10 years, in the Rostov Region, mainly forest cultures of Crimean pine have been created [7].

In the research region, this tree species is introduced. Within the boundaries of the native habitat (Crimea (Russia), Western Transcaucasia (Georgia), and the Mediterranean countries (Turkey)) it grows on calcareous and loamy soils [8-10]. The ecological properties of the tree species – drought tolerance, heat resistance, tolerance to soil fertility – significantly expanded its distribution area [3, 8, 11]. In the Russian Federation, Crimean pine cultivation began in the end of the 19th and beginning of the 20th centuries, and at present it is one of the highly-demanded tree species used for artificial
reforestation and afforestation. It is recommended for planting on lands unclaimed in agriculture, in developed quarries of the foothills of Transcarpathia in Ukraine [11]. There is successful experience in creating forest cultures of Crimean pine on the sandy soils of the steppe zone of Russia [1-3, 7].

The issue of ensuring high survival rate rates of forest cultures has been addressed in many countries around the world. The most promising and effective technique is the use of ball-rooted planting stock (hereinafter referred to as BRPS). In many countries of Northern Europe, South America, Canada and the USA, the creation of BRPS cultures is a priority. In particular, in Finland and Sweden, the share of BRPS in reforestation is about 90% [12].

Following the example of European countries, since the late 1960s BRPS began to be used in the north of the European part of Russia [13]. At present, a regulatory standard for phased increase of the BRPS share in artificial and combined reforestation has been legislatively introduced at least of 20% of the total area – from 01/01/2022, 30% – from 01/01/2025, and 45% – from 01/01/2030 [6]. The advantages of BRPS, however, do not protect against the negative consequences of its use. In climatic conditions identical with the Scandinavian countries – in the European North – the seedlings showed deformation of the stems (saber-shaped curvature) and root systems, damage by insects. The root system of briquetted seedlings has few mycorrhizal endings, which reduces resistance to root rot. On loamy and moist sandy loamy soils, soaking of cultures planted in microdepressions was observed, and on sandy soils – slow growth (by the age of five forest cultures had a height of no more than 40 cm). In addition, the use of BRPS does not guarantee high preservation of plants, especially in areas with good development of natural woody and grassy vegetation [13]. As for the use of BRPS in the southern regions of Russia (forest-steppe, steppe zone), it is aptly noted that a mechanistic replication of the Scandinavian technology with almost complete absence of local experience in the production of forest cultures will not give the expected (positive) results [12]. This means that the bare-rooted planting stock traditionally cultivated in forest nurseries will be in demand in the medium term and up until there is convincing evidence to the contrary.

The standardization of Crimean pine planting material has changed over time in the direction of increasing age and, therefore, biometric indicators. Thus, according [14], 1-year-old seedlings by the min. top length of 10 cm and the min. stem thickness of 1.5 mm in the root collar area were considered standard for the steppe zone of the European Russia (ER). Since in July 1, 1991 new parameters of the standard have been established: age – 2-3 years, the thickness of the stem at the root collar – min. 3 mm, the top length – min. 10 cm [15]. In relation to the Crimean pine seedlings cultivated in the steppe zone, the National Standard of the Russian Federation "Reforestation. Technical conditions" [16] brought into force on June 1, 2018, retained the biometric indicators adopted in 1991. This standard is valid to this day [6].

In other countries of the native habitat of Crimean pine, where it is cultivated in forest nurseries, the reverse trend of changing standards for planting material has been revealed over time. In particular, in the Republic of Turkey (Turkey), the main indicators for planting material standardization are: root collar diameter (RCD), stem height (SH) and the stiffness coefficient – the weight coefficient (K), determined by the ratio of the seedling’s herb mass to the mass of roots in the absolutely dry state [9]. A constant indicator was RCD. Varietal differentiation of seedlings was carried out according to the height of the stem (grade I, II or III), and within each variety – according to the value of the stiffness coefficient (grade I<sub>sc</sub>, II<sub>sc</sub>, III<sub>sc</sub>). The standard of Turkey 1976y [9] establishes 9 varieties for the planting material. The minimum requirements for RCD were 3 mm, and the stem height was set to minimum 9 cm for grade I, min. 7 cm for grade II, and min. 5 cm for grade III. The standard of Turkey 1988y [9] defines 4 varieties, with the RCD requirement reduced to 2 mm, and the stem height for grades I and II was min. 9 cm and min. 7 cm, respectively. A comparison of the biometric indicators of seedlings – RCD and SH – in the standards of the Republic of Turkey and the USSR standards that were in force at that time showed that:

- only the first grade seedlings meet the requirements of the Russian standard for height;
- before 1988, the requirements for RCD are higher in the Turkish standards, and since 1991 – in the standards of the Russian Federation;
the weight coefficient (K) used in the Turkish standards has never had an analogue in the standards of the Russian Federation.

According to the literature data, the planting material cultivated in the Republic of Turkey does not fully comply with the requirements of the standard. Thus, when analyzing the biometric and weight indicators of seedlings grown from seeds collected in different regions of Turkey, it was found that 85.5% of seedlings do not meet the standard of Turkey 1988y requirements and 62.7% do not meet the standard of Turkey 1976y requirements [9]. Each indicator has a significant degree of variation (ν = 33.4–68.8), which may indicate either an imperfection of the technology for growing the planting material, or poor performance of certain technological operations [9, 10].

Almost all of the forestries in the investigated region are provided with basic nurseries. Their production capacity allows for fully meeting the needs for planting material [4-5]. However, in the period of 2002–2017 there was a tendency towards a decrease in the producing area of nurseries. For a number of reasons (high density of seedlings, insufficient watering, damage by pests and diseases, etc.), not all grown seedlings reached standard sizes. According to an inventory conducted by the authors, in 2017 only 35.8% of the total number of seedlings grown met the standard. In absolute terms, this amounted to 1,200,000 pcs. To ensure reforestation activities (the creation of forest cultures and supplementation) 1,500,000 pcs. were required. Thus, the total amount of the standard planting material grown was insufficient to meet the planned volumes of reforestation. The missing amount of planting material is made up for by acquiring it in other regions. The climatic conditions of the steppe zone are such that planting of forest cultures must be carried out for no more than 2 weeks. Therefore, delivery of the planting material to the forest area from a distance of more than 100 km is associated with both economic and environmental losses. In the first case, this means an increase in the cost of work due to transportation costs; in the second case, the guarantee of viability of the planting material cannot be confirmed.

An alternative to non-local planting material can be one cultivated in basic nurseries, but having slight deviations of biometric indicators from the standard. During the inventory it was also found that most of the non-standard seedlings do not meet the requirements by only one indicator – the diameter of the stem at the root collar. Therefore, a hypothesis has been put forward about the possibility of using seedlings that are standard in height, but do not meet the standard in diameter of the root collar, when creating forest cultures. To increase the adaptive properties of seedlings and stimulate root formation, local application of growth-regulating compounds is possible. As applied to seedlings of standard sizes when creating forest cultures on loose sandy soils, their effectiveness was proved earlier [17].

An analysis of literary sources shows that the problem of providing reforestation with standard planting material is not unique to Russia. Literary information (both in Russia and in other countries) regarding the possibility and conditions of using non-standard seedlings for planting on the forested area is practically absent. A priori, when creating forest cultures, planting material must meet the requirements of the standard. However, the data on the actual ratio of seedlings of different quality indicate the possibility of using seedlings of non-standard sizes. For countries with developing economies, the current study is relevant.

The purpose of the study is to identify possible positive (or negative) consequences of using non-standard Crimean pine seedlings when creating forest cultures on sandy soils.
2. Methodology

For purpose achievement it was supposed to analyze the survival rate of Crimean pine forest cultures created by seedlings of non-standard sizes, and substantiate the possibility and conditions of use of seedlings with sizes below the requirements of the standard on soils of light particle size distribution.

2.1. Location and characteristics of the experimental work site

The object of the study was Crimean pine forest cultures created in 2017 on the territory of the Kolundaevsky precinct forestry of the Sholokhov forestry of the Rostov Region (block 30, section 13) in a medium-hilly landscape (figure 1a).

![Image of location map](a) ![Image of experiment options](b)

**Figure 1.** The location map of the experimental site (a) and experiment options (b). Definition of the experiment option ciphers is given in the section 2.2.

The region where the site is located belongs to the steppe zone with a sharply continental climate. Briefly, it can be described as follows: relatively hot and dry summers, moderately cold winters, lack of precipitation and mainly rainfall during the growing season, periodically (after 2–3 years) repeated droughts [2, 3, 17]. According to the calculated value of the hydrothermal coefficient (HTC), it was found that over the previous 65 years, wet conditions of the warm period (HTC = 1.6–1.3) were observed 2 times, slightly arid (HTC = 1.3–1.0) – 9 times [17].

Weather conditions in the year of forest planting and the following two years of observation (2018–2019) were favorable for plant growth. The indicators of the temperature and humidity regime of the vegetation period were higher than long-term average values. The actual amount of precipitation was 589, 668 and 597 mm in 2017, 2018, and 2019, respectively (with an average annual value of 496 mm). The amount of precipitation during the growing season exceeded the norm by 39.8, 58.9 and 38.3% in 2017, 2018 and 2019, respectively. It should also be noted that for 30 years of meteorological observations, the warm period of 2018 was also the wettest - the actual amount of precipitation exceeded the standard by 1.9 times. Adverse factors were the later dates of the last frost: in 2017 – May 20, in 2018 – June 2 (average date – April 20 [18]).

On sandy soils during the period of active growth of the aboveground and underground parts of plants, not only the amount of precipitation, but also the uniformity of their precipitation is of no small importance. In 2017, the maximum number of days with no precipitation was recorded in late April – early May – 12 days. In May – June 2018, three consecutive non-rain periods of 12–15 days were observed. In 2019, the longest period without precipitation, 19 days, was recorded from the end of the third decade of May [18].
The soils on the site are cohesive sand, with a physical clay content of 5 to 10%, due to the features of the relief they are layered (the humus horizon is buried by aeolian sediment). Quartz grains prevail in the chemical composition of hilly sand (97–99%). There is a small amount of macronutrients: phosphorus – from 0.05 to 0.4%; potassium – within 2%; calcium – from 3 to 4%; sulfuric acid salts – from 0.1 to 0.2%; chlorine – from 0.3 to 0.6%; sodium – from 0.3 to 0.7%. The maximum detected thickness of humus layers reaches 55 cm, the humus content in the upper soil horizon does not exceed 0.22% [1, 17].

2.2. Materials and methods
Forest cultures were created in the spring of 2017 using furrows cut by the RN-60 cultivator in the autumn of the previous year. The distance between the centers of the furrows is 3 m. Planting step: in experimental cultures – 0.7 m (density – 4762 pcs/ha), in the control – 0.8 m (density – 4167 pcs/ha).

In total, there are four options for creating forest cultures (figure 1b):
- hand planting with standard seedlings (HS);
- hand planting with non-standard seedlings (HNs);
- hand planting with non-standard seedlings with preplant treatment of seedlings – soaking root systems in Kornevin solution for 6 h (HNsR6);
- mechanized planting with standard seedlings – control (MS).

The control option were cultures created by a single row planter PFC-1. When loading the planting machine into the hopper, the seedlings had long, thin roots trimmed. Each experimental version was laid in fivefold repetition. Planting material used at the experimental facility was grown in the Pigarevsky Forest Nursery – the basic nursery of the Sholokhov Forestry (Rostov region, Russian Federation). The soil of the nursery is thick, chernozem-like cohesive sand on ancient alluvial sand deposits.

Sandy soils are friable [1,3], and the use of seedlings with a height of less than 10 cm increases the risk of falling asleep and lateral buds, and with an increase in wind speed of 5 m/s or more, the risk of damage to the trunks by sand particles (pinching). Consequently, the likelihood of the death of the plant when staying under a layer of sand increases. Therefore, for seedlings of non-standard sizes for carrying out experimental work, certain requirements were nevertheless presented:
- the height of the stem is not less than 10 cm (corresponds to the standard);
- stem diameter at the root collar (thickness) – from 2.0 to 2.9 mm (67–97% of the standard).

Seedlings were selected using technical means: vernier caliper – for measuring the diameter of the stem at the root collar (with an accuracy of 0.1 mm) and a standard ruler - for measuring height (from the root collar to the apical kidney).

In the region, there is successful experience in the use of growth-regulating compounds when applied locally on the forested area [17]. Therefore, in relation to seedlings of non-standard sizes, it was also decided to test the agrotechnical method – preplant treatment of root systems with a solution of a drug that stimulates root formation. Of the variety of such compounds, the most affordable (primarily in terms of the price) is Kornevin [19]. Kornevin produced by LLC Agrosintez (Russian Federation) in the form of soluble powder is included in the “State Catalog of Pesticides and Agrochemicals...” [20]. The chemical belongs to the auxin type of plant growth regulators. It stimulates formation of lateral roots, accelerates the growth of the root system. The main active ingredient is indolybutyric acid (IBA); the preparation also contains macro- (K, P) and microelements (Mo, Mn). The content of the active substance in the preparation is 5 g/kg. The drug is low hazard (hazard class 3), which allows you to prepare a working solution directly in the field. The drug is not phytotoxic – the possibility of an overdose is excluded [19]. The preparation of a Kornevin solution was carried out in the field at the rate of 1 g of the drug per 1 liter of water (until complete dissolution). The exposure time of the root systems of seedlings in the working solution was consistent with the recommendations of the manufacturer of the drug and amounted to 6 h. The flow rate of the working solution is 1 liter per 1 plant [19].
2.3. Work in field and office conditions
For three years (2017–2019), at the beginning (BGS) and in the end of the growing season (EGS), accounting work was carried out: the number of viable plants was calculated. Rooted Crimean pine plants were classified as viable in the presence of the following symptoms: needles of dense green or dark green color, pronounced turbidity, growth of the apical shoot is equal to or more than the growth of lateral branches, trunks are straight, and there is no damage caused by phyto- and entomous pests. The base calculated indicator for assessing the state of forest cultures created using standard and non-standard seedlings, adopted survival rate – the ratio of the number of viable plants to the total number of seats, expressed as a percentage [6].

The obtained data were processed by mathematical statistics methods [21] by STATISTICA 10. The average value (x̄) and its error (± m), variance (s²), standard deviation (s), and coefficient of variation (v) When constructing the diagrams, the error bar was used to reflect the error of the studied indicators. Based on the calculation results, a comparison of the obtained indicators is made. The significance of differences between them was evaluated using two criteria – Student (t) and Fisher (F). If the calculated value of the coefficients (t and F) exceeded or was equal to the tabular value at a 5% significance level, then a conclusion was drawn about significant differences between the studied parameters in the compared options. The presence of significant differences was a sufficient basis for confirming (or refuting) the hypothesis about the possibility of using seedlings of non-standard sizes to create Crimean pine forest plantations.

3. Results and discussion
The result of reforestation measures is the assignment of young growth plots to the lands on which forests are located. The criteria and indicators of such lands are reflected in regulatory documents [6]. One indicator is the number of main trees that have been preserved. According to the results of the inventory of forest cultures in the first year of their growth, one can judge the effectiveness of reforestation in order to justify the subsequent action plan.

An indicator of the success of creating forest cultures is their survival. If the inventory establishes the death of more than 75% of planted plants, forest cultures are recognized as dead [6]. Unfortunately, not all seedlings transplanted from the nursery to the forest cultural area are able to adapt to new forest conditions. The results of a 3-year study indicate that the death of cultivated plants on the forested area occurs annually, but the largest part (21.2–60.1%) occurs precisely in the 1st year (figure 2). Subsequently, the dynamics of mortality decreases: during the 2nd year of growth another 1.8–12.1% of plants died, and in the third year of growth, 0.8–4.7%.

![Figure 2. The survival rate of Crimean pine forest plantations by the experiment options during the period from 2017 to 2019.](image-url)
Hand planting a priori has the advantage, since the integrity of the root system is maximally preserved. Therefore, a higher survival rate of forest cultures throughout the entire period of research is logical. The use of mechanization means provides for trimming part of the root system of seedlings when they are loaded into the hopper of a forest planting machine. This is the main cause of mass death of plants (60.1%) in the first growing season. According to EGS 2017, the survival rate of forest cultures in the control option (MS) was on average 1.5 times less than in hand planting created cultures (options HNs, HS, and HNsP6). Over the next 2 years, despite a significant decrease in the number of dead plants, differences in survival between the experimental options persist. By EGS 2018, the control of preserved plants was 1.8-2.0 times less; by EGS 2019, it was 1.6–1.8 times less.

In the hand planting options for creating forest cultures significant differences in survival rate depending on the quality of the used planting material were not identified. In the first growing season, differences in survival rates between the HS and HNs options were 0.5%, for 2 years – 6.8%, for 3 years – 2.5%. At 2 year growth, seasonal differences in mortality dynamics were noted. When using standard seedlings, most of the plants died in the spring-summer period (4.7–7.4%), when using non-standard seedlings, in the autumn-winter period (9.7%). Stimulation of root formation in seedlings of non-standard sizes (option HNsP6) had a positive effect. In the first growing season, minimal loss of plants was recorded here (10.2%). In subsequent years, the number of surviving plants is comparable to or slightly inferior to that of other options for the hand planting method of creating forest cultures. The reason is the variation of forest conditions even within small areas, which is a feature of hilly sand [1, 3, 17].

Analysis of the dynamics of survival of forest cultures over 3 years shows that when hand planting creating forest cultures, along with standard ones, seedlings with a diameter of the root collar smaller than standard sizes can be used. Stimulation of root formation for them on cohesively sandy soils is not a prerequisite. Large volumes of reforestation provide a mechanized way of creating forest cultures as mandatory. In this case, the use of non-standard seedlings is possible, but subject to mandatory stimulation of root formation.

Our data on the survival rate of forest cultures hand planting created using seedlings of non-standard sizes are generally consistent with the trend in the effectiveness of artificial reforestation achieved in other countries of the world [11, 22]. The territory of the native habitat of Crimean pine (Pinus pallasiana D. Don) is the Republic of Turkey. According to [22], the area of the pine plantations is 4,200,000 ha. Of these, 1.8 million ha are degraded to varying degrees and require reforestation. Another 2,400,000 ha of plantations are located in semi-arid and arid climatic conditions.

During an experiment in the province of Eskişehir (northeastern slope 1115 m above sea level), forest cultures created by 2-year-old seedlings were planted for 8 years with plants 3.0 m by 1.5 m. The soils of the site are sandy loam (the proportion of clay fractions is 14%). The calculated percentage of preserved plants (in % of the number of plants planted) was: at the end of 3 years of growth, 87.3–95.8%, 5 years, 84.1–86.6%, 8 years, 84.1–86.6% [22]. Differences in survival rate, in comparison with the data of our study (figure 2), which constitute at least 22–28% and maximum 31–36% after 3 years of growth, are explained, firstly, by the difference in the granulometric composition of soils; secondly, planting material used in our studies had non-standard sizes.

Almost a century and a half of experience in introducing Crimean pine in the steppe zone of the Russian Federation shows a fairly high tolerance of the breed to soil conditions. In the studies we conducted earlier, it was found that in the conditions of a flat relief on humus-linked coarse sand soils, the survival rate of forest cultures after 3 years of growth is 85–90% [7]. As can be seen, with identical quality of planting material (standard seedlings) and technology of development of the territory (hand planting), survival rates obtained in the introduction zone and in the native habitat are identical [22].

Within the borders of the former Soviet Union, the territory where the experience of introducing Crimean pine can be characterized as satisfactory is the Transcarpathian region of Ukraine. Here, in the middle mountains on uncomfortable agricultural lands, plantation-type forest cultures have been created [11]. The method of creating cultures – hand planting sowing of seeds (6 pcs. in one sowing
place). Placement of sown areas of 1.5 m by 1.0 m. Tillage was carried out only in places of sowing. Sites were located in the upper part of the slope of the southern exposure and in the lower part of the slope of the southwestern exposure. According to a set of environmental indicators: well-heated locations with thin soils, type of forest growing conditions, fresh Sudabra (C2) – the conditions in the experimental sections were identical to the conditions of mountain Crimea, where Crimean pine is an indigenous species [11]. According to the results of the autumn inventory in the first year of forest culture growth, 95% of the sown areas were with seedlings, which indicates the compliance of the ecological conditions of the plots with the bio-ecological requirements of the tree species. However, after a year, survival rate decreased to 63% on the upper part of the slope and to 57% on the lower.

When comparing the conditions and results of our study (figure 2) and the ones mentioned above, we note that only the insolation conditions at the sites can be called roughly identical. According to other indicators, mainly soil fertility, the plots in the Transcarpathian region had an advantage. Nevertheless, the efficiency of reforestation on hilly sand, even when using a non-standard planting material, is higher than in Transcarpathia.

The calculated value of survival of forest cultures cannot be the only objective indicator of the effectiveness of reforestation. It is also necessary that viable plants, in addition to their total number, be placed on the site as evenly as possible. The uniformity of placement is reflected by the indicators of variation in survival rate. Here, across the options of the experimental cultures, differences are observed in the nature and the variation profile of the studied indicator (table 1).

Table 1. Variation of the main statistical indicators of survival rate of Crimean pine forest plants in the period of 2017–2019.

| Experiment option | The value of the main statistical parameters | Experiment option | The value of the main statistical parameters |
|-------------------|---------------------------------------------|-------------------|---------------------------------------------|
|                   | \(\bar{x} \pm m\) | \(s^2\) | \(s\) | \(v\) | \(\bar{x} \pm m\) | \(s^2\) | \(s\) | \(v\) |
| HS                | 86.4±4.7 | 110.3 | 10.5 | 12.2 | 85.9±3.7 | 68.7 | 8.3 | 9.6 |
| MS                | 58.4±8.0 | 317.7 | 17.8 | 30.5 | 89.8±3.7 | 67.2 | 8.2 | 9.1 |
| BGS 2018          | HS 77.0±8.3 | 346.3 | 18.6 | 24.2 | HNs 78.8±9.0 | 406.8 | 20.2 | 25.6 |
|                   | MS 39.9±9.3 | 435.6 | 20.9 | 52.3 | HNsP6 73.4±8.0 | 321.2 | 17.9 | 24.4 |
| EGS 2018          | HS 69.6±7.1 | 254.3 | 16.0 | 22.9 | HNs 76.4±8.8 | 384.2 | 19.6 | 25.7 |
|                   | MS 38.4±12.2 | 743.9 | 27.3 | 71.0 | HNsP6 69.9±6.0 | 178.3 | 13.4 | 19.1 |
| BGS 2019          | HS 69.2±10.6 | 447.4 | 21.2 | 30.6 | HNs 66.7±12.2 | 592.3 | 24.3 | 36.5 |
|                   | MS 38.1±9.5 | 360.8 | 19.0 | 49.9 | HNsP6 62.5±9.1 | 329.5 | 18.2 | 29.0 |
| EGS 2019          | HS 64.5±9.1 | 410.3 | 20.3 | 31.4 | HNs 65.3±10.9 | 599.0 | 24.5 | 37.5 |
|                   | MS 37.3±8.3 | 346.5 | 18.6 | 49.9 | HNsP6 59.3±6.8 | 230.4 | 15.2 | 25.6 |

\(\bar{x}\) – the average value; \(\pm m\) – error of the average value; \(s^2\) – dispersion; \(s\) – standard deviation; \(v\) – coefficient of variation.

The minimum values of variance and standard deviation during the entire observation period are noted in option HNsP6. This means that the stimulation of root formation during preplant treatment of seedlings of non-standard sizes contributes not only to an increase in the survival rate rate during the first year, but also to a decrease in its variability in the subsequent. As a result, the most uniform distribution of plants over the area of the plot is noted. In the control option (MS), the standard deviation and dispersion are significantly higher, that is, a mechanized landing does not ensure uniformity of survival.
The value of the coefficient of variation in the survival rate of hand planting created cultures \((v = 9.1–37.5\%)\) indicates that the population is mostly homogeneous. When using standard seedlings, the variability of the studied indicator \((v = 22.9 \div 31.4\%)\) is generally less than in the case with non-standard planting material \((v = 25.6 \div 37.5\%)\). The variability of survival rate in the option with the treated root systems of non-standard seedlings in a Kornevin solution was the smallest \((v = 9.1 \div 29.0\%)\), which indicates the positive effect of the tested agronomic technique. When using means of mechanization, plants in forest cultures do not form a homogeneous aggregate \((v = 30.5\div71.0\%>25.0\%)\).

Thus, an analysis of the survival rate and the main statistics of its variation shows that the use of seedlings with a stem thickness of 2.0–2.9 mm does not contribute to a decrease in the number of viable plants on cohesive sandy soils. An additional agricultural method is the treatment of root systems in a Kornevin solution that helps to increase survival during the first growing season and further ensures an even distribution of plants on the forested area.

The final conclusion about the possibility of using seedlings of non-standard sizes should be made based on a comparison of the results obtained using the criteria for the significance of differences. Compared to each other options for creating forest cultures hand planting did not reveal a significant effect of the quality of planting material on survival (table 2).

Table 2. The value of the coefficient of significance of differences in the survival rate of Crimean pine forest plants between the compared options.

| Options       | The significance of differences in the survival rate of forest cultures by Student’s criterion \((t_f)\) for the survey period | The significance of differences in the survival rate of forest cultures by Fisher’s criterion \((F_f)\) for the survey period |
|---------------|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
|               | EGS 2017\(^a\) | BGS 2018\(^a\) | EGS 2018\(^a\) | BGS 2019\(^a\) | EGS 2019\(^a\) | EGS 2017\(^a\) | BGS 2018\(^a\) | EGS 2018\(^a\) | BGS 2019\(^a\) | EGS 2019\(^a\) | BGS 2019\(^b\) | EGS 2019\(^a\) |
| HS – HNs      | 0.084          | 0.146          | 0.603          | 0.157          | 0.059          | 0.007          | 0.022          | 0.364          | 0.025          | 0.003          | 0.025          | 0.003          |
| HS – HNsP6    | 0.571          | 0.312          | 0.034          | 0.479          | 0.458          | 0.326          | 0.097          | 0.001          | 0.229          | 0.209          | 0.001          | 0.229          |
| HS – MS       | 3.026          | 2.967          | 2.207          | 2.186          | 2.209          | 9.157          | 8.801          | 4.870          | 4.780          | 4.881          |
| HNs – HNsP6   | 0.748          | 0.448          | 0.613          | 0.273          | 0.467          | 0.560          | 0.200          | 0.376          | 0.075          | 0.218          | 0.075          | 0.218          |
| HNs – MS      | 3.128          | 2.997          | 2.530          | 1.850          | 2.038          | 9.786          | 8.982          | 6.400          | 3.421          | 4.152          |
| HNsP6 – MS    | 3.579          | 2.723          | 2.319          | 1.857          | 2.048          | 12.808         | 7.414          | 5.379          | 3.450          | 4.195          |

In the tinted cells, the actual value of the Student and Fisher coefficients is greater than the standard value at the 5% level. \(^{a} t_{0.05} = 2.31, F_{0.05} = 5.32; ^{b} t_{0.05} = 2.45, F_{0.05} = 5.99.\)

Differences in the survival rate of forest cultures created by both standard and non-standard seedlings are insignificant at a confidence level of 5% over the entire observation period \((t_f < t_{0.05}, F_f < F_{0.05})\). Stimulation of the root formation of seedlings of non-standard sizes with the tested exposure time in a Kornevin solution (6 h) also did not lead to significant differences in survival. There is a tendency toward a decrease in the differences between options HS and HNs, which indicates a high adaptive potential of seedlings of non-standard sizes when planted on cohesive sandy soils.

Compared with the control, significant differences in the survival rate of forest cultures are observed in all of the options incorporating the hand planting creation method, regardless of the quality of the planting material used \((t_f > t_{0.05}, F_f > F_{0.05})\). Stimulation of root formation allows obtaining significant differences over a longer period (table 2).

Survival rate is a relative indicator that allows assessing the efficiency of forest cultures’ creation as early as in the first years of their growth. Its high value shows that by the age of transfer to the lands on which forests are located the created forest cultures will meet the regulatory requirements [6]. On cohesive sandy soils, high survival rate can also be achieved by using seedlings of non-standard sizes, including the treatment of root systems with growth-regulating substances.
4. Conclusion

The result of a three-year study and taking into account the revealed differences indicates that the use of Crimean pine seedlings of non-standard sizes (with a stem thickness of 2.0–2.9 mm at the root of the root collar) does not reduce the quality of reforestation measures. The obtained result also allows us to formulate the conditions under which the use of non-standard seedlings is possible: on cohesive sandy soils when using the manual method of forest culture creation and mandatory stimulation of root formation with a minimum exposure time of at least 6 h on cohesively sandy soils and at least 12 h on loose sandy soils when using the mechanized method of creation.

The main purpose of plantations cultivated on the bumpy sands of the steppe zone is antideflation. The timber obtained by cultivation of such stands is not the main product. Unfortunately, methods allowing for prediction of subsequent development of the plantation based on the assessment of the morphological parameters of the used seedlings have not been developed yet. The obtained positive result of the experiment indicates that the use of non-standard seedlings allows for solving the problem of shortage of planting material. The introduction of agricultural technology – preplant treatment of root systems of non-standard seedlings with Kornevin solution – may additionally provide a more uniform preservation of plants in the forested area.

Crimean pine is increasingly used to create anti-erosion and reforestation plantations in arid regions, both within the natural area and beyond. In many countries of the world, where this tree species is grown in forest nurseries, up to 50% or more of seedlings are non-standard sizes. Such planting material, as a rule, is not used and is disposed of. The research results obtained by us on soils of light granulometric composition in the introduction zone allow us to qualify them as a successful scientific experiment. Therefore, in identical forest growing conditions in other regions of the world – in Turkey, in Ukraine – we recommend using seedlings of non-standard sizes with mandatory pre-planting processing.

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