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ORIGINAL ARTICLE

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# Prospects of cultivation of Jack pine (*Pinus banksiana* Lamb.) on sandy soils of natural–technogenic origin in Kyiv Polissia

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## Abstract

The aim of the research was to identify the influence of environmental factors inherent in the alluvial and displaced sands of the study region on the growth of the Jack pine and the prospects for its cultivation. We found that the success of growth of Jack pine seedlings on sandy soils depends on a set of factors, which include the presence or absence, in the rhizosphere of sand, of humus impurities and genetic horizons of zonal soils, silty or loamy layers, soil density and composition of pine stands formed in the cultivation. On alluvial sands, sparse forests of Jack pine and Scots pine with a density of 0.3 units were formed. The yield of seeds from Jack pine cones was 1–2% higher than the normative values, and the mass of 1000 seeds was 50% higher. Jack pine seedlings grow according to I class of productivity on displaced sands, with an admixture of humus mass and remnants of genetic horizons of zonal soils at the root depth. In the rhizosphere of the stand, the roots of Jack pine seedlings occupied 78% of the mass of all roots that inhabited a metre-thick sand. Jack pine seedlings that fall under the canopy of Scots pine fall out of the plantations due to drying, which indicates their demand for light and appropriateness of growing Jack pine in solitary plantings or in mixed low-density plantations with Scots pine.

## Key words

biometric indicators, displaced sands, sandy soils, seed production, soil occupancy by roots, quality indicators of seeds

## Introduction

Sandy soils located within Kyiv Polissya are usually of anthropogenic origin. In the conditions of unsatisfactory water regime inherent in these sands and lack of mineral nutrients, the species composition of woody plants capable of forming biologically stable plantations on them is quite limited due to inhibition of growth processes in aboveground organs of woody plants (Brovko et al. 2020, 2021).

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This, in turn, causes a decrease in the outflow of carbohydrates and other organic substances to the root systems, which is visually manifested in excessive elongation of the lateral roots as well as a decrease in the total mass of sucking roots (Steele et al. 1997). That is why only ultra-oligotrophic plants, including Jack pine (*Pinus banksiana* Lamb.), are able to settle on sandy soils and grow relatively successfully. In general, this species of pine is a pioneer woody plant. However, with age, there is a decline in growth intensity, which negatively affects their quantitative and qualitative indicators and requires clarification of the ecological properties of sands in each individual area subject to phytomelioration (Vasiliauskas and Chen 2002).

On evaluating the forestry properties of Jack pine according to the literature, we found that it is characterised by frost and drought resistance and unpretentiousness to soil conditions. The species is less affected by pests, including beetle larvae. It has decorative bright green needles; fragrant resin released on the shoots enriches the air with volatile compounds and makes it desirable in plantations of peri-urban areas (Brovko and Brovko 2007). Populations of this species of pine are characterised by the phenomenon of dissemination, and therefore, the scattering of mature seeds from cones occurs only after forest fires, which create elevated air temperatures in the centres of its growth (Greene and Johnson 2000; Pellerin and Lavoie 2003).

Within the natural range, this species of pine is cultivated in boreal conditions. However, in most cases, it is used during the reclamation of lands disturbed by the extraction of oil sands (Proemse et al. 2016). Under such growing conditions, the survival and biometric indicators of Jack pine are negatively affected by the lack of nitrogen and organic matter in the rhizosphere (Farnden et al. 2013). Improvement of survival (by 12–22%) and growth intensity is achieved by feeding pine seedlings with different doses of wood ash (Bélanger et al. 2021).

Within Ukraine, Jack pine had been planted in the Lower Dnieper sands, where it is not inferior to drought resistance, frost resistance and growth intensity in height up to 10 years of age, although in older plantations, there is a decrease in biometric rates and significant damages in the trees caused by pests (Babenko and Tarasenko 1968; Pirohova 2016). In Kyiv Polissia, Jack pine plantations in 8–10-year-olds suffer more from snowfall than Scots pine. Jack pine (Jp) in the mixed plantations with 50% of Scots pine (Sp) and 50% of Jp at the age of 35 years lags behind in growth in height from Scots pine, resulting in the formation of stands with the composition of 7Sp3Jp. On the sandy soils of Zhytomyr Polissia, Jack pine is already at the age of 11 inferior to the biometric indicators of Scots pine by 14–18%. It is also suffered of wind blow on the dump technosoils covered with humus mass of zonal soils (Brovko and Brovko 2007). In general, studies conducted in the western part of Small Polissia in Ukraine show that cultivating this species of pine as the main forest species is advisable only in very dry boreal and protoboreal sites, provided that protective plantations are created. Jack pine also could be used in sites after fires, where it should be grown as an impurity to Scots pine (Guz' et al. 2003, 2007; Yuskevych et al. 2019).

Scots pine is the most common species on the sands of natural and man-made origin in the study area. Scots pine is cultivated as the main forest-forming and phytomeliorative species and its share in such plantations usually reaches about 90%. Jack pine is planted only sporadically in a small capacity and mainly as an admixture to Scots pine on these sands. Its response to a range of environmental factors inherent in the sandy soils of the study area has not yet been fully described in the literature, and in order to have a detailed forestry knowledge related to its cultivation on alluvial and displaced sands, we conducted this study. Note that the displaced sands are sands that have been moved and levelled on the land's surface as a result of working of earthmoving equipment (excavators, bulldozers).

The main purpose of the work was to study the biometric indicators and seed yield in Jack pine seedlings growing on sandy soils of natural and man-made origin in the study area and to assess their suitability for cultivation of seedlings of this species.

## Material and methods

Jack pine (experimental plots) and Scots pine (control plots) plantations planted at different intervals on the sand dam of the Kyiv Reservoir served as the objects of research. The sand dam had been formed on the left bank of the Dnieper River in 1961–1964 during the construction of the Kyiv hydroelectric power plant. The sand dam begins from the dike of the Kyiv hydroelectric power plant and limits the contours of the left bank of the reservoir in the northern direction to a distance of more than 39 km by a strip 300–600 m wide. Geographical coordinates of the dam are as follows: in the North – 50°55'40'' NL and 30°35'54"–30°35'56" EL; in the South – 50°35'14" NL and 30°31'39"–30°31'43" EL. The dam was filled with sands of glacial and alluvial origin, which are common in this area. These sands were moved (we call them displaced sands) by earthmoving techniques (in the contour) and washed on (inside) during the formation of a profile of the dam from the deposits of anthropogenic period, which were deposited on a terrace of the Dnieper River floodplain and directly in the riverbed. This land area is the protective zone of the Kyiv reservoir. The plantations were created by the State Enterprise 'Vyshche-Dubechnia Forestry', and now they are part of its forest fund. The technology of creating plantations within the studied area was the same. Pre-planting tillage was carried out with a forest plough, with the width on the furrow bottom being 70 cm. The furrows of 15 cm deep were arranged in 1.5–2.5 m along the longer side of the plot. Annual seedlings of Jack pine and Scots pine were planted in early spring using Kolesov's sword with a planting distance of 0.5 m. Sands were loosened and weeds were weeded in rows for 2 years. The loosening was carried out twice in the year of planting and three times in the next year. Temporary trial plots (TTP) were laid in a rectangular shape. The size of the TTP was determined from the presence of such a number of trees, which would ensure the determination of biometric indicators with an accuracy of 5%.Their width was set equal to or as a multiple of the width of the scheme of mixing woody plants, and the length was taken into account that available on the trial plot quantity of the trees, provided 5% accuracy in determining biometric indicators. The diameter of tree trunks was measured at a height of 1.3 m, and the height was measured in two to three trees of each thickness level (diameter classes) with an accuracy of 0.25 m. Heights for individual thickness levels were aligned graphically, according to their measurements in the studied trees. The average biometric indicators of Jack pine and Scots pine plantations were determined by the methods used in forest biometrics (Grom 2007), as well as by tables of growth and productivity of stands (Bilous et al. 2020).

The population of the upper 1 m layer of sand occupied by pine roots was determined by the monolith method (Kolesnikov 1972; Böhm 1979). Soil samples with roots were taken with a soil drill (with a cross-sectional area of 55.39 cm$^2$ and a working surface height of 10 cm) to a depth of 1 m, with sampling done every 10 cm. Roots isolated from monoliths were divided into small (up to 2 mm thick, which are conventionally classified as physiologically active roots) and coarse (over 2 mm thick, which are considered skeletal and perform conductive functions). The mass of roots extracted from the monoliths, after drying in a thermostat at a temperature of +105°C, weighed on laboratory scales, and the results obtained, separately for the selected fractions and layers, were transferred to an area of 1 m$^2$ of plot.

Harvesting of cones and seeds of Jack and Scots pines was carried out in February. Biometric parameters of Scots pine and Jack pine cones were determined in ninefold repetition, and sowing qualities of their seeds were found in accordance with the National Standards of Ukraine: NSU 5036:2008 (2009) and NSU 8558:2015 (2017). The determination was performed in two replicates. A total of 16 seed samples were examined, 100 seeds in each. Laboratory and absolute seed germination were determined using equations 1 and 2, respectively:

$$LG = (n \times 100) \times N^{-1} \quad (1)$$

$$AG = (n \times 100) \times (N - a)^{-1} \quad (2)$$

where:
LG – laboratory germination,
AG – the absolute germination in %,
$n$ – the amount of seeds that germinated in the sample,
$N$ – the amount of seeds in the sample taken for germination,
$a$ – the amount of empty seeds in the sample.

The average values of the biometric indicators were calculated using statistical methods (Chiang 2003; Borovikov 2013), and the significance of the difference between the obtained data was evaluated by Student's *t*-test.

## Results and discussion

The plantations with Jack pine on the sandy soils of the study region reached 18–33 years of age at the time of the survey, which allowed us to make some generalisations about the feasibility of its cultivation under such growing conditions. As we found out, the success of the growth of Jack pine on the sands depends on a number of factors. Such indicators include the proportion of silty fractions in the sands, their completeness, as well as the characteristics of plantations formed in the process of their cultivation, namely the composition and density of plantings. The latter is important because Jack pine is quite sensitive to shading of the crown (Brovko and Brovko 2007). Some biometric indicators of pine plantations growing on alluvial sands are shown in Table 1.

**Table 1.** Comparative analyses of biometric indicators of pine plantations growing on alluvial sands

| TTP | Indicators | Species | | Differences from Scots pine | |
|---|---|---|---|---|---|
| | | Scots pine ‘control’ | Jack pine | % | t |
| Rovzhiv forestry | Composition of plantation – 10Sp + Jp. Block 106, plot 4. Age – 22 years | | | | |
| | Height [m] | 9.2 ± 0.41 | 7.3 ± 0.39 | −20.3 | 3.4 |
| | Diameter [cm] | 14.2 ± 0.69 | 11.5 ± 0.85 | −19.0 | 2.5 |
| | Square of crown projection [m$^2$] | 7.99 ± 0.30 | 5.80 ± 0.36 | −27.4 | 4.7 |
| | Current increment in height [cm] | 41.3 | 33.2 | −19.6 | – |
| | Class of productivity | I | II | – | – |
| Pirnovo forestry | Composition of plantation – 10Sp + Jp. Block 119, plot 4. Age – 26 years | | | | |
| | Height [m] | 4.8 ± 0.06 | 4.7 ± 0.17 | −2.1 | 0.7 |
| | Diameter [cm] | 5.3 ± 0.16 | 6.0 ± 0.71 | 13.2 | 1.0 |
| | Current increment in height [cm] | 18.5 | 18.1 | −2.2 | – |
| | Class of productivity | IV | IV | – | – |

Note: Tabular value of the quantiles of the Student’s *t*-test (*t*) at a probability level of 0.05–1.96.

Jack pine was planted as an admixture with Scots pine (one row Sp + Jp mixing scheme) with 2.0 × 0.5 m placement of planting sets on TTP 1. At the time of the survey, sparse forests with a density of 0.3 units were formed. According to the study results presented in Table 1, on alluvial sands with a soil compactness in the upper layer of 1.50–1.66 g/cm$^3$, Jack pine, in 22 years of age, reached a height of 7.3 m and Scots pine reached 9.2 m, which corresponds to II and I classes of productivity, respectively. The differences between the height, diameter and square of the crown projection in the examined seedlings were significant ($t$ = 2.5–4.7). At the same time, the studied indicators in Jack pine were 19–27% lower than in Scots pine plantations. But the affiliation of Jack pine seedlings to the second class of productivity indicates the possibility of growing the species on alluvial sands as an admixture with Scots pine stands.

Both pine species are not able to form highly productive plantations and grow according to IV class productivity on alluvial sands (Tab. 1). In plantations where Jack pine was planted as an impurity to Scots pine with a mixing scheme of two rows Sp + Jp and two rows of willow (*Salix acutifolia* Willd.) with the placement of planting sites being 1.5 × 0.5 m (TTP 2), the plantation of 0.61 unit density was formed in 26 years of age. It should also be noted that the willow, at the time of the survey, completely fell out of the stand, and the difference in growth of pines in height was insignificant ($t$ = 0.7) and was only 2%, indicating the unsuitability of sands with such density for formation of plantations of phytomeliorative purpose with their participation.

The success of survival and further growth of pine plantations on the sands formed by their replacement depend on the presence or absence of loam or inclusions of humus mass of zonal soils in the rhizosphere of sand layers. In this case, the productivity of pine stands varies from III to I$^a$ class of productivity (Brovko et al. 2021). At the same time, the success of Jack pine cultivation also depends on a set of factors, the most significant of which is anthropogenic impact, which is manifested not only in the choice of strategic directions of phytomeliorative development of sands, but also in fires. The presence of Jack pine trees with cones in fires contributes to its natural settlement within the surrounding areas (Fig. 1). However, periodic recurrence of dry periods during the growing season affects the survival of woody plants planted on sands, and in the case of prolonged action, can even cause their death.

The growth conditions of pine on displaced sands are slightly different from those on alluvial sands, as evidenced by the biometric indicators of the plantations given in Table 2. TTP were set in Pirnovo forestry in

**Figure 1.** Jack pine self-seeding, which appeared on the sands after the fire. Rovzhiv Forestry: block 88, plot 7. Age – 8 years.

sparse plantations (TTP 3) and closed stand with a density of 0.91 (TTP 4). The main biometric indicators of pine plantations growing on the sands formed by their mechanical replacement are shown in Table 2.

As found in Table 2, Jack pine seedlings have a smaller current increment in height (22.0–35.7%) than Scots pine seedlings. Jack pine seedlings have also a smaller growth of trunk in height (22.4–35.2%) than Scots pine seedlings on displaced sands in the case of mixing in one row (TTP 3, 4). It is also worth noting that Jack pine seedlings, in the area where sparse forest was formed due to fire (TTP 3), at the age of 32, were inferior (by 26.0–35.7%) to Scots pine according to all studied biometric indicators. At the same time, the difference in the studied indicators was significant ($t$ = 4.3–20.8) and outweighed the theoretical values of the Student's $t$-test ($t$ = 1.96).

On sands with inclusions of humus mass of zonal soils and with an admixture of loams (TTP 4), Scots pine and Jack pine are capable of growing on I$^a$ and I class of productivity, respectively. High-density stand

**Table 2.** Biometric indicators of pine plantations grown on displaced sands

| TTH | Indicators | Species | | Differences from Scots pine | |
|---|---|---|---|---|---|
| | | Scots pine 'control' | Jack pine | % | t |
| | Composition of plantation – 10Sp + Jp. Block 83, plot 10. Age – 32 years | | | | |
| 3 | Height [m] | 8.8 ± 0.11 | 5.7 ± 0.10 | −35.2 | 20.8 |
| | Diameter [cm] | 22.3 ± 0.98 | 16.5 ± 0.91 | −26.0 | 4.3 |
| | Square of crown projection [m$^2$] | 17.2 ± 0.27 | 11.7 ± 0.72 | −32.0 | 7.2 |
| | Current increment in height [cm] | 27.2 | 17.5 | −35.7 | – |
| | Class of productivity | III | IV | – | – |
| | Compositions of plantation – 7Sp3Jp. Block 83, plot 3. Age – 33 years | | | | |
| 4 | Heigh [m] | 16.5 ± 0.06 | 12.8 ± 0.10 | −22.4 | 31.7 |
| | Diameter [cm] | 17.0 ± 0.36 | 11.5 ± 0.30 | −32.4 | 11.7 |
| | Current increment in height [cm] | 50 | 39 | −22.0 | – |
| | Density | 0.64 | 0.27 | −57.9 | – |
| | Stock of trunk wood [m$^3$/ha] | 211 | 73 | −65.0 | – |
| | Class of productivity | I$^a$ | I | – | – |

Note: Tabular value of the quantiles of the Student's $t$-test ($t$) at a probability level of 0.05–1.96

(0.91 unit of closure) was formed in the 33-year–old plantation, which was created according to the scheme of mixing 1rPs1rJp and with the placement of planting sites 2.0 × 0.5 m. This stand had a composition of 7Ps3Jp and a stock of 284 m$^3$/ha.

At the same time, Jack pine seedlings lagged significantly behind in growth (by 22.4%) and trunk diameter (by 32.4%) compared to Scots pine seedlings. The seedlings of Jack pine, under the canopy of Scots pine, dried up and fell out of this plantation. This fact indicates the high demand for light by Jack pine and the expediency of its cultivation in solitary plantings or in low-density plantations mixed with Scots pine.

The influence of environmental factors on the natural regeneration of pine in the boreal forests of northwestern Quebec was studied by Beland and Bergeron (1993). They concluded that significantly higher densities of advanced growth of Jack pine were observed in the following descending order: fresh fluvio-glacial sands, dry shallow organic soils over bedrock and moderately dry fluvio-glacial sands, compared to the other ecological types which showed no Jack pine regeneration. The regression model developed by them showed that the share of sand content in horizon B had a positive effect on the processes of pine regeneration (regression coefficient was +0.01).

On sandy soils, Jack pine forms a branched root system (Fig. 2). In the case of joint cultivation with Scots pine (TTP 4), the metre-thick layer of sand was more intensively inhabited by Jack pine roots. In 33-year-old plantations, the largest population of sand by roots (4186 g/m$^3$) was observed in the rows of Jack pine, where it owned 89% of the mass of roots in the metre-thick layer of sand. Between the rows of the studied pines, the roots of Jack pine were dominated. We found 3816 g of Jack pine roots in 1 m$^3$ of sand that was 78% of the total weight of roots.

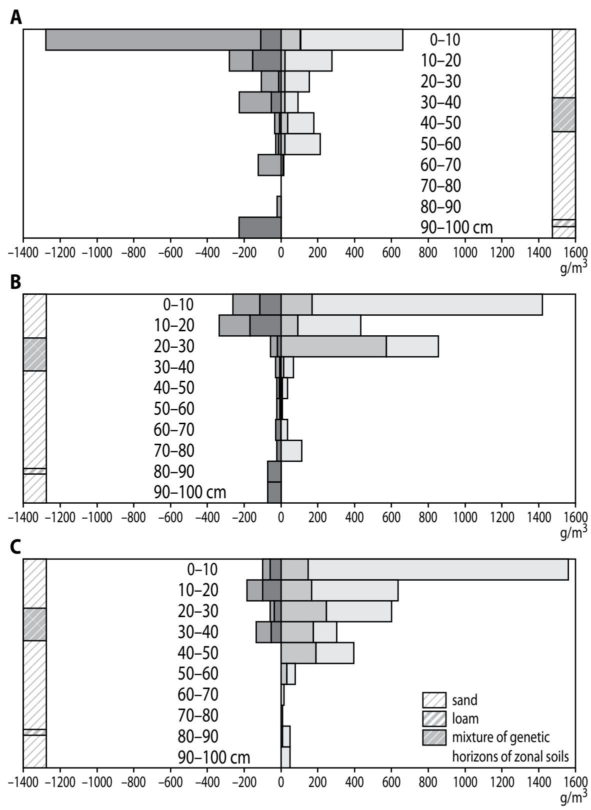


**Figure 2.** Population of a metre–thick layer of displaced sands with pine roots in a 33-year–old stand with a composition of 7Sp3Jp: A – in the Scots pine rows; B – between the Scots pine and Jack pine rows and C – in the Jack pine row

The mass of Jack pine roots was the lowest in the rows of Scots pine. However, their share was 40% of the total mass of roots, considered in a metre thickness (3869 g/m$^3$), which indicates the dominance of its roots in the rhizosphere of plantations, while growing along with Scots pine.

The mass of physiologically active roots of Jack pine exceeds the mass of skeletal (coarse) roots in rows of Scots pine by 7.1 times, between rows of Scots pine and Jack pine by 2.4 times and in rows of Jack pine by 2.7 times, and the share of physiologically active Jack pine roots in the upper 30-cm layer occupies 69%, 89% and 82%, respectively. This clearly indicates the surface branching of Jack pine roots and the dominance of its roots in the rhizosphere space between rows.

The root systems of Jack pine, aspen and spruce were studied by Steele et al. (1997) in the forests of two contrasting climatic zones of Canada. Their results showed that the length of physiologically active roots and their biomass were smaller in Jack pine than in the other two studied tree species.

Chrosciewicz (1990) points to a close relationship between the germination of pine seeds and the conditions of the object at the time of sowing. The scientist came to the conclusion that plantings of seed origin can be characterised by better survival, trunk shape and growth rates of biometric indicators.

Given that the reproductive capacity of woody plants is one of the factors that reflect their adaptation to environmental conditions of growth, we investigated the quality of conifer and seed yield in 29-year-old seedlings of Scots pine and Jack pine growing in block 83, plot 4 of Rovzhiv forestry. These studies are presented in Table 3 and are shown in Figure 3.

The obtained data showed that cones of Jack pine are dominated by Scots pine cones: in length (4.8 ± 0.06 cm) and mass of one cone (6.34 ± 0.06 g) by 6.2% and 14.3%, respectively; by the number of seeds in a cone (72 ± 3.03 pcs) and yield of seeds in cones (3.7 ± 0.12%) by 200% and 42%, respectively. Also,

**Table 3.** Biometric indicators of Scots pine and Jack pine cones collected in a 29-year-old plantation growing on displaced sands

| Indicators | Species | | Differences from Scots pine | |
|---|---|---|---|---|
| | Scots pine ‘control’ | Jack pine | % | t |
| Length [cm] | 4.2 ± 0.60 | 4.8 ± 0.06 | 14.3 | 1.0 |
| Diameter [cm] | 2.2 ± 0.15 | 1.6 ± 0.01 | −27.3 | 4.0 |
| Mass of one cone [g] | 6.0 ± 0.19 | 6.3 ± 0.06 | 5.0 | 1.5 |
| Number of seeds in the cone [pc.] | 24 ± 0.85 | 72 ± 3.03 | 200.0 | 15.2 |
| Seed yield from cone [%] | 2.6 ± 0.11 | 3.7 ± 0.12 | 42.3 | 6.8 |

Note: Tabular value of the quantiles of the Student’s *t*-test (*t*) at a probability level of 0.05–2.45.

only the diameter of the cones of Jack pine was less (by 27.3%) than that of Scots pine cones.

Cones from Jack pine can vary in shape and size, but are usually skinny and curved and are 2.5–8 cm long. They are yellowish, brown and stay tightly closed unless they experience high temperatures (Alexander and Cruz 2012).

It should also be noted that the seeds in the collected cones of Scots pine had a variable colour. At the same time, one cone contained seeds that had a skin colour from light grey to dark brown shades. Of the total number of seeds contained in the cones, up to 34% had a light grey skin colour. The yield of seeds from the cones on the displaced sands was higher than the normative values (1–2%) and was 2.6 ± 0.11% and 3.7 ± 0.12% for Scots pine and Jack pine, respectively.

Jack pine cones are usually recommended to be extracted for 6 h at an air temperature of 65°C and humidity of 27% (Payne 1955). According to our observations, cones open well after 15 min in a thermostat at 90°C. The cones partially opened (Fig. 3, item 4), which reduced the effort to separate the scales from the rod (cone axis).

On determining the quality indicators, we found that the collected seeds are characterised by the phenomenon of parthenospermia. In our opinion, this phenomenon is primarily due to the unsatisfactory water


**Figure 3.** Cones and seeds collected in a 29-year-old pine plantation growing on displaced sands: (a) cones: (1, 2) – Scots pine, with varying degrees of severity of the apophysis surface, (3, 4) – Jack pine, with a smooth apophysis shape – before heat treatment (3) and after 15 min of heating in a thermostat at a temperature of 90°C (4); (b) seed with lionfish: (5) – Scots pine, (6) – Jack pine; (c) general type of seeds: (7) – Scots pine, (8) – Jack pine

regime of sands within the rhizosphere of pines grown on sands. The coefficient of saturation of sand pores with moisture within the rhizosphere during the growing season is in the range of 0.03–0.21 units, which is 4–26% of the optimal value (0.8 units). Secondly, the low content of basic (NPK) mineral nutrients (less than 2 mg/100 g of sand) is also reflected in the quality indicators and biometric indicators of seeds (Tab. 4, Fig. 3).

Jack pine seeds, harvested from the cones of its seedlings growing on sandy soils, are smaller than those of Scots pine and, according to the studied biometric indicators, are inferior to it in length (by 11.9%), in diameter (by 25.9%) and in mass of 1000 seeds (by 50.0%).

The obtained indicators of absolute energy of seed germination on day 7 and its germination on day 14 in the studied species of pines indicate the absence of significant differences ($t_r$ = 1.4–1.5) in seed germination during this period, because the difference reached only 2.1–3.5%. However, data on absolute germination show that Jack pine seeds germinate extremely well on the third day after sowing (68 ± 1.3%), because the germination of its seeds during this period was 66% higher than that of Scots pine seeds. A significant difference in the studied pine species (*t* = 4.5–13.1) was observed for germination energy in the first 5 days.

In addition, the empty content of seed in Jack pine was 24% ± 0.6% (one of the four seeds was empty). This is 31% less than in the studied seeds of Scots pine (35 ± 1.2%), where one of the three seeds was empty. Data given in Table 4 show that in the case of harvesting seeds of Jack pine and Scots pine in plantations growing on displaced sands, improving seed's quality from III to I class can be done by the separation of empty seeds from filled seeds.

**Table 4.** Quality indicators of Scots pine and Jack pine seeds harvested in 29-year-old plantation growing on displaced sands

| Indicators | | | Species | | Differences from Scots pine | |
|---|---|---|---|---|---|---|
| | | | Scots pine 'control' | Jack pine | % | t |
| Length [mm] | | | 4.2 ± 0.14 | 3.7 ± 0.10 | −11.9 | 2.9 |
| Diameter [mm] | | | 2.7 ± 0.07 | 2.0 ± 0.03 | −25.9 | 9.2 |
| Mass of 1000 seeds [g] | | | 6.4 ± 0.23 | 3.2 ± 0.08 | −50.0 | 31.1 |
| Germination energy for day 7 [%] | technical | | 56 ± 2.1 | 66 ± 0.09 | 17.8 | 4.4 |
| | absolute | | 85 ± 1.8 | 88 ± 0.8 | 3.5 | 1.5 |
| Germination | technical in day [%] | 3 | 27 ± 1.5 | 51 ± 0.9 | 88.9 | 13.7 |
| | | 5 | 48 ± 2.5 | 63 ± 0.4 | 13.1 | 5.9 |
| | | 7 | 56 ± 2.1 | 66 ± 0.9 | 17.8 | 4.4 |
| | | 10 | 60 ± 1.8 | 70 ± 0.8 | 16.7 | 5.1 |
| | | 14 | 62 ± 1.9 | 72 ± 0.8 | 16.1 | 4.8 |
| | absolute in day | 3 | 41 ± 1.6 | 68 ± 1.3 | 65.9 | 13.1 |
| | | 5 | 73 ± 2.3 | 84 ± 0.8 | 15.1 | 4.5 |
| | | 7 | 85 ± 1.8 | 88 ± 0.8 | 3.5 | 1.5 |
| | | 10 | 91 ± 1.1 | 94 ± 0.6 | 3.3 | 2.4 |
| | | 14 | 94 ± 1.0 | 96 ± 1.0 | 2.1 | 1.4 |
| Among the ingeminated | empty | | 35 ± 1.2 | 24 ± 0.6 | −31.4 | 8.2 |
| | healthy | | 3 ± 0.4 | 3 ± 0.8 | 0 | – |

Note: Tabular value of the quantiles of the Student's *t*-test (*t*) at a probability level of 0.05–2.45.

## Conclusion

The success of the growth of Jack pine seedlings on sandy soils depends on a set of factors. Among these, in addition to the content of impurities in the sands (silty, loamy, etc.), a prominent place belongs to their density, as well as the composition and density of the plantations formed in the process of their cultivation.

On alluvial sands where Jack pine seedlings were planted as an admixture with Scots pine, a forest with a density of 0.3 units was formed. Jack pine at the age of 22 reached a height of 7.3 m, which corresponds to II class of productivity. At the same time, the indicators studied in Jack pine (height, diameter and area of crown projection) were 19–27% smaller than in Scots pine, but they indicated the possibility of its cultivation under such ecological growth conditions.

Jack pine grows according to I class of productivity on displaced sands with inclusions of humus mass and remnants of genetic horizons of zonal soils at the root depth. High-density (0.91 units) stand of Jack pine with a composition of 7Sp3Jp and a stock of trunk wood of 284 $m^3$/ha was formed in 33-year-old plantation created with a scheme of mixing row of Scots pine in row of Jack pine with the placement being 2.0 × 0.5 m. At the same time, the roots of Jack pine seedlings dominated in the rhizosphere. In particular, in the rows of Banks pine, they owned 89% of the mass of roots, which were a metre thick, and between the rows of Scots pine and Jack pine, they owned 78%. Seedlings of Jack pine in the aboveground space lagged significantly in height (22.2%) and trunk diameter (32.4%) from the seedlings of Scots pine. Seedlings that fell under the canopy of Scots pine withered and fell out of the plantation, which indicates their fastidiousness to the light regime and the appropriateness of cultivating this species in solitary plantings or in low-density plantations mixed with Scots pine.

Jack pine cones harvested from seedlings growing on displaced sands were dominated by Scots pine cones: in length (6%) and in weight of one cone (14%), by the number of seeds in the cone (by 200%) and the yield of seeds from the cones (by 42%). Seed yield from cones was higher than the normative values (1–2%) and was 3.7 ± 0.12%. Jack pine seeds are smaller than Scots pine seeds and are inferior to them in length (by 11.9%), in diameter (by 25.9%) and in mass of 1000 seeds (by 50.0%). The absolute germination of Jack pine seeds on day 3 after sowing was 68 ± 1.3%, which is 65.9% more than that of Scots pine. The proportion of empty seeds among ingeminated seeds was less by 31%.

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