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PRODUCTIVITY OF SEEDLINGS OF SCOTS PINE ON ALLUVIAL SANDS OF NATURAL AND MAN-MADE ORIGIN

Purpose. To find out quantitative physical and water indicators for which there are significant changes in forest vegetation properties in alluvial sands, as well as to trace their impact on the formation of pine seedling root systems and the accumulation of aboveground phytomass in their plantations.

Methodology. The chemical properties of sandy soils were determined taking into account the current requirements of ISO, and their physical and water properties using volumetric cylinders, followed by the calculation of their density, porosity, as well as the coefficients of water content and aeration. The root population of the upper meter layer of sands was determined by the method of monoliths, and plant productivity was assessed by phytomass of medium model trees (7-year-old seedlings, plots 1–4) and by biometric indicators (22-year-old seedlings, plots 5–9).

Findings. It was found that on alluvial sands with a density of 1.50–1.66 g · cm^{-3} in their upper meter thickness, 7-year-old seedlings of Scots pine form a superficial root system (1341.8 g · m^{-2}), which provides accumulation of 2558 kg · ha^{-1} of aboveground phytomass in seedlings. As the density of sands increases, the production of seedling phytomass decreases. In the case of an increase in density by 1–4 % (1.52–1.72 g · cm^{-3}), there is a decrease in the mass of roots, in a meter-thick layer of sand (by 53.4 %) and aboveground phytomass (by 36 %). An increase in the density of sands by 5–10 % with its maximum values (1.74–1.79 g · cm^{-3}) in a 10–30 cm layer causes a decrease in the mass of pine roots by 64.1 %. The roots of pine seedlings, for such a density of sand, are not able to inhabit the inter-row space, as indicated by their content in the upper 20-cm layer of sand (2 % of the mass of small roots recorded in a one-meter thickness). The phytomass of aboveground organs decreased by 81 %, and the seedlings themselves were marked by "dwarf" growth (were grown by V class of productivity). On sands covered with humus mass of zonal soils, the one meter thickness contained fewer (by 51.4 %) pine roots (482.8 g · m^{-2}) than on the control. The share of small roots was smaller (by 61.5 %) and that of coarse roots was higher (by 21.5 %). Losses of aboveground phytomass per unit area in pine seedlings growing under such conditions can reach 31 %, due to the compaction of sands at a depth of 25–50 cm (1.67–1.72 g · cm^{-3}) when they are covered by humus mass and row spacing are overgrown with herbaceous plants (root mass in 60-cm profile 3147 g · m^{-2}) in the phase of their individual growth.

Originality. Quantitative indicators of density, porosity and coefficients of water content and aeration of alluvial sands of natural and man-made origin are shown for which the seedlings of Scots pine feature delay in the formation of full-fledged root systems of the surface type, which is reflected in a decrease in the productivity of pine plantations cultivated on the sands, up to the visual manifestation of their "dwarf" growth.

Practical value. The quantitative indicators of their physical and water properties obtained for alluvial sands explain the changes occurring in the structure of the root systems of Scots pine seedlings and the productivity of their aboveground organs. Maintaining the density of sands in the range of 1.50–1.66 g · cm^{-3} will allow growing pine seedlings on sands without covering their surface with humus mass, and no-till pre-planting loosening of sands in the rows of future crops allows ensuring the cultivation of multifunctional pine plantations.

Keywords: *Scots pine, sand, phytomass, phytomelioration, density, moisture*

Introduction. Sands, according to their forest vegetation properties, belong to the most extreme proto-pine series of trophotopes. They are characterized by low water holding capacity (up to 6 %), and therefore, in the absence of water-retaining (silty) layers in their thickness, precipitation is not able to stay in the sand layer and penetrates deep to the water table. Due to the weak capillary capacity of sands (2–3 cm), moisture is not able to rise, which negatively affects the water balance of their recultivation layer throughout the growing season [1]. In the absence of genetically determined horizons, sandy lithozems undergo deflation and pollute the environment with products of water and wind erosion. The area of such sands within Ukraine reaches about 120 thousand hectares [2]. The formation of highly productive phytocenoses, which would be characterized by biological stability and durability, is quite difficult due to unsatisfactory water, physical and chemical properties of sands, and therefore the search for effective phytomeliorative measures for their recultivation refers to extremely relevant, yet not entirely clarified environmental problems that already need to be addressed nowadays.

Literature review. Scientists engaged in phytomelioration of sandy lithozems have found that the renewal of biota in such landscapes is naturally delayed for decades (Izyumova, O.G., 2016), and for the cultivation of forests that would effectively perform phytomeliorative functions should form a recultivation layer with a thickness of 80 to 140 cm [3]. Currently, for the reclamation of sands it is proposed to use various peat-mineral mixtures [4] and deep no-till loosening in the rows of future plantations [1], but the most effective methods include dumping humus mass of zonal soils on their surface followed by natural regeneration of woody plants growing in the surrounding areas [5, 6]. In cases of lack of humus mass or in its absence, the complex studies are usually envisaged with methods that ensure the retention and preservation of moisture in the recultivation layer of sands (Brovko, F., Brovko, O., Tanchyk, S., & Yuchnovskyi, V., 2020), [7] and even the use of halotolerant bacterial cells to cement their surface [8]. In general, these studies help to control the forest vegetation properties formed on sandy landscapes and allow predicting the most probable directions of their phytomelioration in advance. At the same time, quite often among the sandy landscapes there are one age seedlings of Scots pine, which, growing within even one row, differ in the intensity of growth by several classes of productivity. At the same time, there are no quantitative indicators of environmental factors in the literature, which show such a difference in the growth of pine seedlings, and scientific explanations for this phenomenon actually remained in the attention of experts in the reclamation of man-made disturbed lands.

Unsolved aspects of the problem. The presence of low productivity plantations of Scots pine with "dwarf" growth (growing in V and lower classes of productivity), which occur not only on dump sands [1, 9], but also on river terraces in pine plantations of natural origin, as well as on sand dunes that are subject to wind erosion [1, 10], prompted us to conduct this study to establish quantitative environmental indicators that cause inhibition of the growth of pine seedlings growing on sands.

Purpose. The main task of the study was to identify environmental factors that cause "dwarf" growth in seedlings of Scots pine, growing on alluvial sands of natural and man-made origin, as well as to find available to phytomeliorators-practitioners agro-technological measures that would effectively prevent this rather negative phenomenon and contribute to the formation of pine plantations on the sands with high reclamation properties.

Methods. The object of our research was 7-year-old cultures of Scots pine, which grew on sands of water-glacial and alluvial origin. These sands were relocated by earthmoving equipment or washed by dredgers during the formation of the protective dam of the Kyiv Reservoir (1961–1964) from anthropogenic sediments deposited on the terrace without loess of the Dnipro floodplain and directly in its bed. The research area is located on the left bank of the reservoir within its sanitary zone and now belongs to the forest fund of Rovzhi Forestry (block 50, unit 5) of the State Enterprise "Vyshche-Dubechna Forestry". Pine seedlings growing within the research area are characterized by visually visible differences in biometric indicators and their safety (Table 1).

Table 1

Biometric indicators of 7-year-old pine seedlings growing on alluvial sands

No	Height, m, · (%–t)$^{-1}$	Diameter of trunk, cm · (%–t)$^{-1}$	Crown projection area, m^2 · (%–t)$^{-1}$	Safety, % · (%–t)$^{-1}$
Alluvial sands, not covered by HMZS				
1	1.22 ± 0.042 100 – –	4.0 ± 0.15 100 – –	0.59 ± 0.044 100 – –	79 ± 2.4 100 – –
2	0.80 ± 0.040 66–7.2	2.9 ± 0.15 72–5.2	0.30 ± 0.033 51–5.3	86 ± 3.5 109–1.6
3	0.51 ± 0.019 42–15.4	2.1 ± 0.13 52–9.6	0.21 ± 0.022 36–7.8	36 ± 0.6 46–17.4
Alluvial sands covered with a 20-cm layer of HMZS				
4	1.45 ± 0.061 119–3.2	4.2 ± 0.23 105–0.7	0.70 ± 0.038 118–1.9	45 ± 0.6 57–13.7

Note. 1. HMZS – humus mass of zonal soils.
2. The tabular value of the quantiles of Student's criterion (*t*) at a probability level of 0.05 – for biometric indicators – 2.02, for safety – 2.31

The height of pine seedlings served as the main criterion for determining the location of the trial plot. Trial plot 1 was laid on sands, where 7-year-old pine seedlings had the best growth (1.22 m). The biometric and environmental parameters obtained in this trial plot served as controls. The difference with the control in the height of the seedlings on TP 2 was 34 %, and on TP 3 – 58 %. TP 4 was laid on sands, where their surface is covered by a 20-centimeter layer of humus mass of zonal soils (sod-podzolic), and the height of seedlings growing in this place exceeded the control ones by 19 %.

Agro-techniques for planting plantations throughout the research area were the same. Pre-planting tillage was carried out with a plow PKL–70. Furrows 15 cm deep were arranged 2.5 m in the direction from south-east to north-west. Annual seedlings of Scots pine were planted in early spring under Kolesov's sword with a planting pitch of 0.4 m. The loosening of sands and weeding in rows was carried out for two years. Two inspections were carried out in the year of planting and in the following year – 3. At the age of 7 the crowns of pine seedlings in rows were closed, and between rows the closure was only 0.4–0.8 units, which indicates the presence of the surveyed plantation in the individual phase growth. This allows us to attribute the difference between the biometric parameters of the studied seedlings to the heterogeneity of growth conditions, which are characteristic of the sands due to a set of technological works to form the profile of the protective dam.

Average sand samples for determination of the content of basic mineral nutrients were taken and prepared for analysis taking into account the requirements of ISO 11464:2007 [11]. The analyses were performed in 3-fold repetition. The content of nitrate and ammonium nitrogen was determined according to ISO 11272:2001 [12], mobile forms of phosphorus and potassium compounds according to Kirsanov's method in the National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky" modification (ISO 4405:2005 [13]), and the acidity level (pH) according to ISO 10390:2007 [14].

Physical and water properties of sandy lithozems were determined 3–5 times by volume cylinders, followed by calculation of their density, porosity, as well as the coefficients of water content and aeration [15, 16].

The population of the upper meter-deep layer of sand with the roots of pine and herbaceous plants was determined by the method of monoliths [17]. Soil samples with roots were taken by drilling (with a cross-sectional area of 55.39 cm^2 and a working surface height of 10 cm) to a depth of one meter with sampling in every 10 cm. The roots, isolated from monoliths, were divided into small ones (up to 2 mm thick, which conditionally referred to as physiologically active) and coarse ones (over 2 mm thick, which are considered skeletal and perform leading functions). The mass of roots, extracted from the monoliths, after drying in a thermostat at a temperature of +105 °C, was weighed on laboratory scales ADV–200, and the results, separately for the selected fractions and layers, were transferred to an area of one square meter of sandy lithozems. Phytomass of medium model seedlings of Scots pine (in TP 1–4) was installed separately on each test plot (taking 5 model trees) by weighing on laboratory electronic scales (TV 404316.002 TE) individual vegetative organs, pre-dried in a thermostat with temperature +105 °C. The fractional and total weight of seedlings obtained during the research was calculated per 1 ha of the plantation area. Setting of temporary trial plots 5–9 and determination of biometric indicators was carried out in compliance with current recommendations [18].

The average values of the obtained data and the statistical significance of the difference between the studied indicators (Student's criterion) were calculated using the STATISTICA application program (Borovikov, V. P., 2018).

Results. Alluvial sands, due to their chemical, physical and water characteristics, are unsuitable for biological reclamation. In particular, the meter thickness of the sands within the dam is characterized by a neutral reaction (pH 6.5 units), as well as content of nitrate nitrogen 2.0 mg and ammonium 1.4 mg, mobile compounds – phosphorus 1.2 mg and potassium 9.0 mg per 100 g of sand. The silty layers washed in the sand layer by dredgers contain more nitrate (by 35 %) and ammonium (by 71 %) nitrogen, mobile compounds of phosphorus (by 67 %) and potassium (by 12 %) than sand, which indicates a rather high probability of the dependence of the phytomeliorative properties of sandy lithozems on the share of silty fractions in their rhizosphere thickness. Determination of the density in the meter thickness of sands showed (Table 2) that in the test plots 1–3, where the surface of the sands was not covered with humus mass of zonal soils, its values were beyond the optimal values. At the same time, the lowest values of sand density (1.50–1.66 $g \cdot cm^{-3}$) and the highest biometric values in 7-year-old pine seedlings were observed in TP 1 (Table 1).

Quantitative indicators obtained in this plot indicate that the density in some layers of sand has increased – on the TP 2 only at 1–4 %, and at the TP 3 – by 5–10 %. With such very insignificant changes in the density of sands, the studied average biometric indicators in pine seedlings decreased by 28–49 % and by 48–64 %, respectively, which actually became the subject of our research. "Dwarf" growth was manifested in pine seedlings, which grew on the TP 3. In this plot, the highest values of sand density (1.75–1.79 $g \cdot cm^{-3}$) were recorded at a depth of 15–30 cm. In our opinion, these density indicators are critical and have become the main reason for the decrease in biological productivity of pine seedlings in the trial plot. Density values close to the optimal ones (0.92–1.01 $g \cdot cm^{-3}$) were observed only in the upper 10-centimeter layer of humus mass of zonal soils dumped on the surface of sands (TP 4). This layer had a density 39–43 % lower than the same layer of sands under control (TP 1). It should also be noted that during pouring on the site of the humus mass and in the process of leveling it on the surface of the site there is more than usual, compaction of sands (5–10 %), and at 35–50-cm depth there was compaction of sands to values, critical for root penetration (1.70–1.72 $g \cdot cm^{-3}$), which indicates the need for phytomeliorative development of sands after their autumn deep loosening.

Differences in the density of sands affected their water and physical properties. In particular, as evidenced by Fig. 1, the highest content of solid particles (84.46–85.51 %) was observed in the upper 10-cm layer of sand, where pine seedlings were marked by the lowest biometric indicators (TP 3), and the lowest (60.91–63.29 %) was in the layer of humus mass of zonal soils, dumped on the surface of the sand (TP 4), where pine seedlings had the highest biometric indicators.

Determination of the porosity of sands in the area (TP 1), which served as a control, showed (Fig. 1) that its indicators in the one-meter thickness of sands at the time of the survey were in the range of 17.2–21.7 %. At the same time, the lowest values (17.2 %) were observed in the upper 10-centimeter layer of sand, and the maximum (21.7 %) – at a depth of 70–75 cm. It should also be noted that the decrease in porosity by 1–6 % of those for the control area (TP 1) causes a decrease in the height of pine seedlings by a third (Table 1), and porosity of 14.5–16.8 % was characteristic of sands, where seedlings pine "dwarf" growth was observed (TP 3).

The humus mass of zonal soils dumped on the surface of sands (TP 4) had porosity of 113–129 % higher (36.7–38.1 %) than that of sands that served as a control (TP 1). The porosity indicators of the sand layer at a depth of 30–60 cm which was covered with humus mass, on the contrary, were by 18–32 % lower than in the control (TP 1) and varied in the range of 16.2–17.1 %. At the same time, the lowest water content (0.43–0.62 %) was observed in the 0–5-cm layer of sand, and the highest (6.87 %) – in the 20–25 cm layer of sand, which contained gleyed impurities of genetic horizons of zonal sod-podzolic soils (TP 4). The existing difference in density and porosity of the studied alluvial sands affected their water prop-

Table 2

Density of the upper meter thickness of alluvial sands, $g \cdot cm^{-3}$. Row spacing of 7-years old Scots pine plantations. Rovzhy Forestry, block 50, unit 5

Depth of section, cm	Without HMZS surface cover:			Covered with a 20-cm layer of HMZS, TP 4
	TP 1	TP 2	TP 3	
0–5	1.61 ± 0.030	1.65 ± 0.021	1.70 ± 0.013	0.92 ± 0.009
5–10	1.66 ± 0.041	1.72 ± 0,09	1.74 ± 0,011	1.01 ± 0,027
15–20	1.62 ± 0.012	1.64 ± 0.038	1.79 ± 0.018	1.64 ± 0.010
25–30	1.59 ± 0.034	1.62 ± 0.017	1.75 ± 0.037	1.67 ± 0.022
35–40	1.57 ± 0.019	1.60 ± 0.010	1.71 ± 0.029	1.70 ± 0.049
45–50	1.56 ± 0.043	1.59 ± 0.024	1.67 ± 0.006	1.72 ± 0.081
55–60	1.53 ± 0.027	1.55 ± 0.013	1.62 ± 0.045	1.67 ± 0.057
65–70	1.50 ± 0.011	1.52 ± 0.022	1.59 ± 0.089	1.61 ± 0.008
75–80	1.50 ± 0.028	1.53 ± 0.031	1.59 ± 0,018	1.62 ± 0.043
85–90	1.50 ± 0.023	1.54 ± 0.007	1.59 ± 0.056	1.62 ± 0.029
95–100	1.50 ± 0.008	1.55 ± 0.040	1.59 ± 0.009	1.63 ± 0.013

Note. 1. HMZS – humus mass of zonal soils.
2. The tabular value of the quantiles of Student's criterion (t) at a probability level of 0.05–2.45

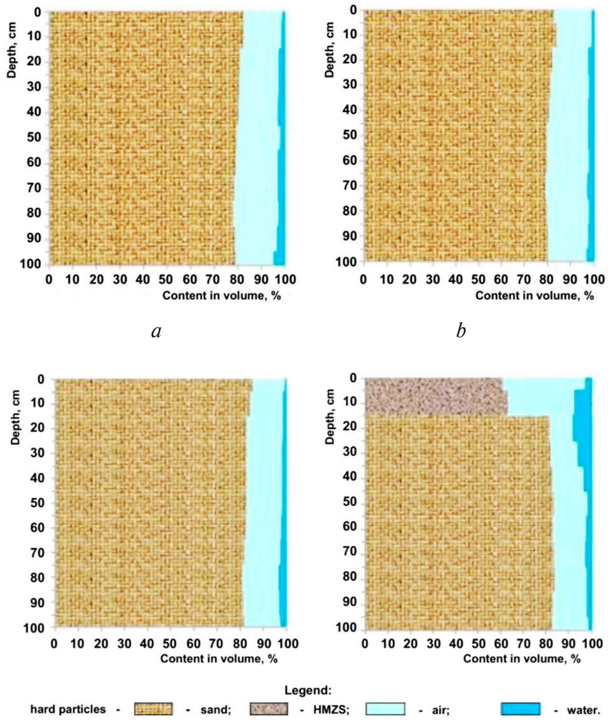


Fig. 1. Content of solid particles, air and water in the upper one-meter thickness of alluvial sands:
a – TP 1; b – TP 2; c – TP 3; d – TP 4

erties. The lowest indicators of moisture saturation of wells (0.03–0.04 units) were observed in the upper 5-cm layer of sands, and the highest (0.21 units) – in the 95–100-cm thickness of sands in the area where TP 1 was laid. However, in all three surveyed trial plots (TP 1, 2 and 3) the coefficients of water saturation of wells in alluvial sands did not exceed 26 % of their optimal values (0.8 units), which indicates a shortage of water resources in a one-meter thickness of sands. Against the background of lack of moisture, the aeration coefficient of sands was 2.8–4.8 times higher than its optimal values (0.2 units) and ranged within 0.56–0.97 units.

Covering the surface of sands with humus mass of sod-podzolic sandy soils only partially improves their water regime, because the water saturation coefficient of humus mass even two days after precipitation did not exceed 0.44 units (55 % of its optimal values). Therefore, this measure does not solve problems associated with the improvement of the water regime of sands, because the water content in them reached only 9–12 % of the optimal values. In general, the low water content of sands is due to their high water permeability, because the rate of water infiltration in the investigated layer of sand is excessively high (589–995 mm $\cdot$ h^{-1}), and the existing layers of silt (up to 2 cm) only reduced the water permeability of sands (by 30–85 %), however, did not provide its optimization.

A study on root systems in rows of 7-year-old pine plantations (TP 1–4) showed that the development of alluvial sands by roots of woody and herbaceous plants depends on the density of sands within the rhizosphere and the presence or absence of humus mass of zonal soils on their surface. On sandy lithozems, where the density of one-meter thickness was in the range of 1.50–1.66 g $\cdot$ cm^{-3} (Fig. 2, *a*, TP 1), pine seedlings formed a fairly well-branched surface root system. At the same time, there were 1341.8 g $\cdot$ m^{-2} of roots in a meter-thick layer of sand, of which 1178.4 g $\cdot$ m^{-2} belonged to small, and 163.4 g $\cdot$ m^{-2} to coarse roots. It should also be noted that the maximum values of small (37.4 %) and coarse (37.9 %) roots were observed

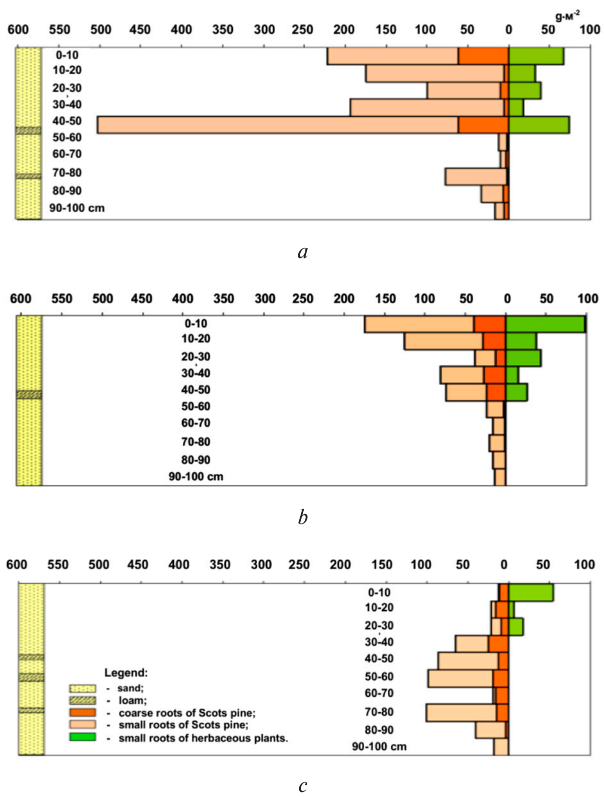


Fig. 2. Population of a meter-thick sand layer by the roots. Interrows of 7-year-old pine seedlings:
a – TP 1; b – TP 2; c – TP 3

in the 40–50 cm thick sand, where the silty layer was exposed, and in the upper 50 cm thickness contained 88.9 % of small and 88.4 % coarse roots, from the sands taken into account in one-meter thickness. This structure of root systems is attributed to the surface type. It is usually characteristic of pine-lichen forests (*Pineta-cladinosa*) Polissia, where plants are fed by water due to precipitation.

The total mass of roots in the one-meter thickness in the test plot 2 (Fig. 2, *b*) where the density of individual layers of sand was only 1–4 % lower than in TP 1 decreased by 53.4 % (small roots by 57.7 %, coarse roots by 17.3 %). That had a negative effect on the accumulation of phytomass by medium model pine seedlings (Table 3).

The maximum values of small (27.6 %) and coarse (28.7 %) roots were observed in the upper 10-cm layer of sand in the test plot and their mass was 85.6 % (81.2 % for small and 96.0 % for coarse roots) in the 50-cm layer of sand. The mentioned relative indicators of the content of root mass in sands, in fact, reflect the degree of deterioration of forest vegetation conditions in the studied area of pine plantations. Particularly noticeable structural changes in the structure of the roots were observed in 7-year-old seedlings of Scots pine, which grew on TP 3, where the density of sands was 5–10 % higher than in TP 1, and in the 5–30 cm layer of sands it acquired maximum values (1.74–1.79 g $\cdot$ cm^{-3}). Under such growth conditions, the total population of pine roots in one-meter-thick sand decreased by 64.1 % (small roots by 69.7 %, coarse roots by 23.5 %). In addition, in places with excessive density of sand, the main mass of the roots of 7-year-old pine seedlings was concentrated within a radius of one meter from their trunks (Fig. 3, *a*) and unable to populate the row spacing in the upper 20-cm layer of sand (Figs. 2, *c* and 3, *a*), because at the time of the survey, it contained only 2 % (7.1 g) of the mass of small and 21.0 % (26.4 g) of coarse roots recorded in a one-meter thickness of sand.

Herbaceous plants settle on the sands in smaller quantities, and the mass of their roots, under such growing conditions, decreases by 13.2–39.7 times compared to the sands covered with humus mass. It should be noted that the maximum root mass (239.2 g $\cdot$ m^{-2}) was observed in the control (TP 1). With increasing density of sands, as can be seen from Figs. 2, *a–c*, the mass of roots decreased by 53.0 % (TP 2) and by 76.9 % (TP 3). On alluvial sands (Table 3, TP 1–3), the largest phytomass (324 g) was accumulated by 7-year-old model pine trees growing on the control (TP 1). Of this mass, the share that belonged to the trunk made 29 %; to branches – 21 %; to needles – 50 %. In the case of increasing density of sands, the total phytomass of model trees decreased by 42–58 %, and within individual organs the decrease in mass was as follows: trunks – 47–80 %; branches – 46–61 %; needles – 37–50 %.

It should be noted that in the total mass of plantations the share of needles increased (by 5–10 %), and the share of mass belonging to the trunk decreased (by 3–15 %), which indicates the adaptation of pine to growth on sands due to structural changes in its overall balance of phytomass. On sands covered with humus mass of zonal soils (Table 3, TP 4), model pine seedlings were marked with a higher mass than in the control (TP 1). Seedlings growing in this plot accumulated more trunk wood (27 %), branches (49 %) and pine needles (1 %) than seedlings growing on sands.

In sands with a density of more than 1.74 g $\cdot$ cm^{-3} there are visually visible deformation of pine roots in the form of bends of a spiral shape, as well as roots that have a flat shape (Fig. 3, *b*). It should also be noted that the roots of pine saplings (TP 3) spread to less dense (1.59–1.67 g $\cdot$ cm^{-3}) sand horizons (50–100 cm). Therefore, the population of small roots of the upper 50-centimeter layer of sand was only 37.5 %, and coarse roots – 57.7 %. Visible mycorrhiza buds, which settle on the sucking roots of pine (Fig. 3), at such a density, are not able to significantly improve the growth of seedlings that grew in V class of productivity.

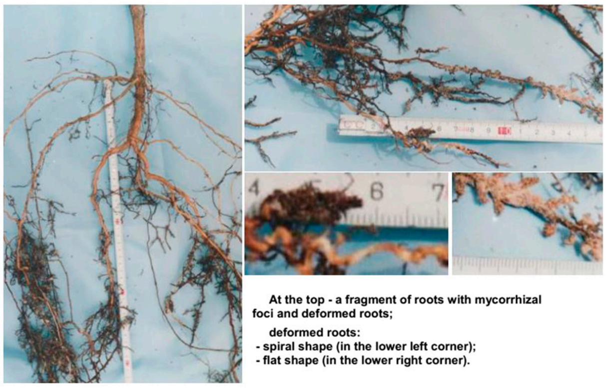
On sands covered with humus mass of zonal soils (Table 4, TP 4), the content of pine roots (482.8 g $\cdot$ m^{-2}) was lower (by

Table 3

Aboveground phytomass of 7-year-old average model seedlings of Scots pine, grown on alluvial sands

No	The mass of the average seedling, g · %$^{-1}$:						Total, g · (%–%)
	trunk	branches	age of needles, years				
			1	2	3	in all	
Sands not covered with humus mass of zonal soils							
1	94 ± 2.7 29–100	67 ± 1.9 21–100	54 ± 1.5 17–100	59 ± 1.7 18–100	50 ± 1.4 15–100	163 ± 4.6 50–100	324 ± 9.2 100–100
2	50 ± 2.1 26–53	36 ± 1.5 19–54	44 ± 1.8 24–81	30 ± 1.2 16–51	29 ± 1.2 15–58	103 ± 4.2 55–63	189 ± 7.8 100–58
3	19 ± 0.6 14–20	35 ± 1.2 26–39	38 ± 1.3 28–70	23 ± 0.8 17–39	21 ± 0.6 15–42	82 ± 2.8 60–50	136 ± 4.6 100–42
Sands covered with humus mass of zonal soils							
4	119 ± 3.2 31–127	100 ± 2.7 26–149	73 ± 2.0 19–135	60 ± 1.6 16–102	31 ± 0.8 8–62	164 ± 4.5 43–101	383 ± 14 100–118

Note. 1. In the numerator – phytomass of individual organs of pine seedlings and the error of their values.
2. In the denominator – the percentage is relative to the total mass of the seedling and relative to the individual organs of the seedling in the TP 1



a *b*

Fig. 3. Root system of a 7-year-old pine seedling on compacted sands (1.74–1.79 g · cm^{-3}), TP 3:
a – general view; b – fragments of roots

51.4 %) than on TP 1. At the same time, the share of small roots in the meter thickness was smaller (by 61.5 %) and that of coarse roots was higher (by 21.5 %). At the same time, in the upper 50-centimeter layer there were 41.0 % of small roots of those that inhabited a meter-thick layer and almost all skeletal roots (96.7 %). Under such growing conditions, this circumstance and the presence of 51.3 % of coarse roots in the upper 10-cm thickness indicate the formation of superficial root system in pine seedlings, which tends to be localized in the humus mass of zonal soils. The interrows of pine plantations in this area are overgrown with a thick carpet of herbal grass plants, among which the terrestrial marten (*Calamagrostis epigeios* (L.) Roth.) prevails. Its roots deepened to a depth of 60 cm, and their mass reached 3147 g · m^{-2}, of which 78.9 % mastered the upper 10 cm layer of humus mass, displacing the small pine roots into deeper horizons of sand. This is evidenced by the population of small pine roots (31.4 %) of the silty layer, which lay at a depth of 60–70 cm.

According to the sum of forest vegetation effect from edaphotopes formed on alluvial sands and taking into account the preservation of pine seedlings during the 7-year growing period, the most effective accumulation of phytomass (2558 kg · ha^{-1}) was observed on TP 1 (Table 5). It indicates the possibility of cultivating pine on sands without covering their surface with humus mass.

With the deterioration of water-physical properties within the rhizosphere of sandy lithosomes, the loss of biomass in pine seedlings can reach 36–81 % (TP 2 and 3), which indicates the need to improve agro-technological measures that would increase productivity and sustainability of pine seedlings on alluvial sands. In the case of growing pine seedlings on sands, the surface of which is covered with a 20-centimeter layer of humus mass of sod-podzolic soils, the loss of total phytomass per unit area in pine seedlings can reach 31 % (Table 5, TP 4), due to two reasons. The first is associated with the compaction of sands during their shelter by humus mass of zonal soils and can be solved by deep shelf-free autumn loosening of furrows, and the second is related to overgrowing with grass plants between rows of pine seedlings during the individual phase of their growth seedlings and can be solved through timely agro-technological care.

Examination of 22-year-old seedlings of Scots pine, which grow on alluvial sands, showed (Table 6) that in the case of pre-planting treatment of sands with furrows (TP 5–6), on them, due to low productivity (grow in IV–V class of productivity (pine seedlings), high-density plantations are formed (0.69–0.97 units), whose functional purpose is limited by phytomeliorative impact on the environment.

Increasing the productivity and biological stability of pine stands on alluvial sands of the study region is possible through the use of pre-planting no-till loosening of sands in the rows of future crops (TP 7), or in the case of covering their surface with a 20 cm layer of humus zonal soil (TP 8 and 9).

Pine plantations planted on the sands loosened by the PRN–40 plow grow according to the II class of productivity and at the age of 22 have a stock of trunk wood of 105 m^3 per 1 ha. Covering the surface of sands with humus mass of zonal soils provides growth of pine stands according to the II class of productivity (TP 8), and in case of combination of this agrotechnological measure with their pre-planting loosening (TP 9) pine seedlings grow according to the I class of productivity and in 22-year age accumulates 142 m^3 of trunk wood (per 1 hectar). That is, productivity is not inferior to plantations that grow on the zonal soils of the study region. At the same time, for forestry reasons, sheltering sands with humus mass of zonal soils does not cause objections, because it significantly improves their forest vegetation potential. To reduce the cost of the biological stage of recultivation, this measure should be performed simultaneously with the formation of the reclamation layer of sandy lithozems.

In general, the data given in Table 6 indicate the effectiveness of deep loosening of alluvial sands and indicate the possibility of growing pine plantations on them for multifunctional purposes.

Conclusions. It is shown that alluvial sands are unsuitable for biological reclamation, and their phytomeliorative poten-

Table 4

Population by the roots of a meter-thick layer of alluvial sands, covered with a 20-cm layer humus mass of zonal soils. Interrow spacing of 7-year-old pine crops (TP 4)

Depth, cm	Root fraction	Scots pine: $g \cdot m^{-2}$	Scots pine: %	Herbaceous plants: $g \cdot m^{-2}$	Herbaceous plants: %
0–10	small	42.3 ± 1.38	9.3	2483.3 ± 112.30	78.9
	coarse	101.7 ± 3.76	51.3	0	0
	total	144.0 ± 2.71	22.0	2483.3 ± 112.3	78.9
10–20	small	66.4 ± 2.20	14.6	361.1 ± 19.64	11.5
	coarse	46.9 ± 2.35	23.7	0	0
	total	113.3 ± 4.35	17.4	361.1 ± 19,64	11.5
20–30	small	31.8 ± 1.94	7.0	58.0 ± 3.31	1.8
	coarse	22.1 ± 0.93	11.2	0	0
	total	53.9 ± 2.84	8.3	58.0 ± 3.31	1.8
30–40	small	26.2 ± 1,19	5.8	30.6 ± 1.65	1.0
	coarse	14.1 ± 0,97	7.1	0	0
	total	40.3 ± 1,30	6.2	30.6 ± 1.65	1.0
40–50	small	19.3 ± 1.46	4.2	101.6 ± 6.46	3.2
	coarse	7.2 ± 1.18	3.6	0	0
	total	26.5 ± 2.08	4.0	101.6 ± 6.46	3.2
50–60	small	18.2 ± 0.99	4.1	112.2 ± 8.93	3.6
	coarse	3.3 ± 0.77	1.7	0	0
	total	21.5 ± 1.56	3,3	112.2 ± 8.93	3.6
60–70	small	142.7 ± 6.01	31.4	0	0
	coarse	2.7 ± 0.55	1.4	0	0
	total	145.4 ± 6.06	22.4	0	0
70–80	small	66.7 ± 4.34	14.6	0	0
	coarse	0	0	0	0
	total	66.7 ± 4.34	10.2	0	0
80–90	small	23.0 ± 1.21	5.1	0	0
	coarse	0	0	0	0
	total	23.0 ± 1.21	5.1	0	0
90–100	small	17.6 ± 1.14	3.9	0	0
	coarse	0	0	0	0
	total	17.6 ± 1.14	2.7	0	0
0–100	small	454.2 ± 18,62	100.0	3147.0 ± 145.00	100.0
	coarse	198.6 ± 8,00	100.0	0	0
	Total	652.8 ± 26,14	100.0	3147.0 ± 145.00	100.0

Table 5

Aboveground phytomass of 7-year Scots pine plantations grown on alluvial sands

No	Phytomass seedlings, $kg \cdot ha^{-1} \cdot (\%)^{-1}$: trunk	branches	age of needles, years: 1	2	3	in all	Total, $kg \cdot ha^{-1} \cdot (\%)^{-1}$
Sands not covered with humus mass of zonal soils							
1	744 100	528 100	423 100	463 100	400 100	1286 100	2558 100
2	429 58	312 59	376 89	256 55	259 65	891 69	1632 64
3	68 9	127 24	136 32	82 18	77 19	295 23	490 19
Sands covered with humus mass of zonal soils							
4	536 72	451 85	328 78	272 59	167 42	767 60	1754 69

Table 6

Biometric indicators of 22-year-old seedlings of Scots pine, grown on alluvial sands. Rovzhy Forestry, placement of planting places 2.0 × 0.5 m, the scheme of mixing 1 row Scots pine

No	Block; unit	Average: height, $m \cdot \%^{-1}$	Average: diameter, $cm \cdot \%^{-1}$	Class of prod.	Density	Per 1 ha: trees, thous,. $pc. \cdot \%^{-1}$	Per 1 ha: stock, $m^3 \cdot \%^{-1}$
Pre-planting treatment of sands PKL–70							
5	57;7	3.8 ± 0.18 100	9.0 ± 0.40 100	IV	0.79 100	3.7 100	23 100
6	57;7	1.7 ± 0.07 45	6.0 ± 0.39 67	V	0.97 123	4.3 116	6 26
Pre-planting loosening of sands, PRN–40							
7	112;2	7.4 ± 0.04 195	8.6 ± 0.20 96	II	0.85 108	3.8 103	105 456
Sands covered with a 20-centimeter layer of HMZS							
pre-planting treatment by PKL–70							
8	50;1	7.6 ± 0.04 200	10.1 ± 0.18 112	II	0.94 119	3.2 86	118 513
pre-planting treatment by PKL–70+PRN–40							
9	114;1	9.0 ± 0.95 237	11.6 ± 0.18 129	I	0.89 113	2.6 70	142 617

tial depends on the presence of silty fractions in their root layer. Sands with a density of 1.50–1.66 $g \cdot cm^{-3}$ are the most suitable for growing pine seedlings. With an increase in the density of sands by 1–4 %, the average biometric indicators of seedlings decrease by 28–49 %, and with a difference of 5–10 %, the losses reach 48–64 %.

It was found that differences in the density of sands affect their physical and water properties. The porosity of 17.2–21.7 % was observed in sands, where pine seedlings had the highest biometric indicators, and the porosity of 14.5–16.8 % was characteristic of sands where pine seedlings had "dwarf" growth. The coefficients of water saturation of pores in alluvial sands did not exceed 26 % of their optimal values (0.8 units), and the aeration coefficients of sands exceeded its optimal values by 2.8–4.8 times (0.2 units).

It was found that on sands with a density of 1.50–1.66 $g \cdot cm^{-3}$ 7-year-old pine seedlings form a superficial root system, which in one-meter thickness contains 1341.8 $g \cdot m^{-2}$ of roots, of which 1178.4 $g \cdot m^{-2}$ are small roots and 163.4 $g \cdot m^{-2}$ are coarse roots and accumulate 2558 $kg \cdot ha^{-1}$ of aboveground phytomass. With an increase in the density of sands by 1–4 %, the total mass of roots, in their one-meter thickness, increases by 53.4 % (small roots by 57.7 % and coarse roots by 17.3 %), and the loss of aboveground phytomass in pine seedlings reaches 36 %. An increase in the density of sands by 5–10 % causes a decrease in the population of one-meter-thick sands with pine roots (by 64.1 %) and the mass of aboveground organs (by 81 %). At the same time, the share of trunk wood and branches in the biomass of seedlings decreases (by 31–84 %), and that of needles increases (by 16–40 %).

The productivity and biological stability of pine plantations on alluvial sands can be increased by using pre-planting no-till loosening of sands in future plantations, or by covering their surface with a 20 cm layer of humus mass of zonal soils in combination with their transplanting deep loosening.

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Продуктивність саджанців сосни звичайної на намивних пісках природно-техногенного походження

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Мета. Встановити кількісні фізичні та водні показники, за яких відбуваються істотні зміни лісорослинних властивостей у намивних пісках, а також простежити їхній вплив на формування у саджанців сосни кореневих систем і накопичення надземної фітомаси в їх насадженнях.

Методика. Хімічні властивості піщаних літоземів визначали з урахуванням чинних вимог ДСТУ ISO, а їх фізичні й водні властивості за допомогою об'ємних циліндрів із наступним розрахунком показників їх щільності, шпаруватості, а також коефіцієнтів обводненості та аерації. Корененаселеність верхнього метрового прошарку пісків визначали методом монолітів, а продуктивність насаджень оцінювали за фітомасою середніх модельних дерев (7-річних саджанців, пп. 1–4) та за таксаційними показниками (22-річних саджанців, пп. 5–9).

Результати. Встановлено, що 7-річні саджанці сосни звичайної на намивних пісках із щільністю в їх верхній метровій товщі 1.50–1.66 г · см$^{-3}$ формують поверхневу кореневу систему (1341.8 г · м$^{-2}$ коренів), що забезпечує накопичення в насадженні 2558 кг · га$^{-1}$ надземної фітомаси. Зі зростанням щільності пісків продукування фітомаси саджанцями зменшується. У разі збільшення щільності на 1–4 % (1.52–1.72 г · см$^{-3}$), має місце зменшення маси коренів, у метровій товщі пісків (на 53.4 %) і надземної маси (на 36 %). Зростання щільності пісків на 5–10 % із максимальними значеннями (1.74–1.79 г · см$^{-3}$) у 10–30-см прошарку, викликає зменшення маси коренів сосни на 64.1 %. Корені саджанців сосни, за такої щільності пісків, не здатні заселяти міжрядний простір, на що вказує їх вміст у верхньому 20-см прошарку пісків (2 % маси дрібних коренів, зафіксованих у метровій товщі). Фітомаса надземних органів у саджанців зменшувалась на 81 % і вони відзначались «карликовим» ростом (зростали за V класом бонітету). На пісках, укритих гумусованою масою зональних ґрунтів, метрова товща містила менше (на 51.4 %) коренів сосни (482.8 г · м$^{-2}$), ніж на контролі. Частка дрібних коренів була меншою (на 61.5 %), а грубих більшою (на 21.5 %). Втрати надземної фітомаси на одиницю площі у саджанців сосни, що зростають за таких умов, можуть сягати 31 %, що зумовлено ущільненням пісків на глибині 25–50 см (1.67–1.72 г · см$^{-3}$) під час їх укриття гумусованою масою й заростанням міжрядь культур сосни трав'яними рослинами (маса коренів у 60-см товщі 3147 г · м$^{-2}$) у фазі їх індивідуального росту.

Наукова новизна. Показані кількісні показники щільності, шпаруватості й коефіцієнтів обводненості та аерації намивних пісків природно-техногенного походження за яких у саджанців сосни звичайної відбувається затримка у формуванні повноцінних кореневих систем поверхневого типу, що відображається у зниженні продуктивності культивованих на пісках насаджень сосни, аж до візуального прояву їх «карликового» росту.

Практична значимість. Отримані для намивних пісків кількісні показники їх фізичних і водних властивостей пояснюють зміни, що відбуваються в будові кореневих систем саджанців сосни звичайної та продуктивності їх надземних органів. Підтримування щільності пісків у межах 1,50–1,66 г · см$^{-3}$ дозволить вирощувати саджанці сосни на пісках без укриття їх поверхні гумусованою масою, а безвідвальне передпосадкове розпушування пісків у рядах майбутніх культур забезпечить вирощування насаджень сосни поліфункціонального призначення.

Ключові слова: *сосна звичайна, пісок, фітомаса, фітомеліорація, щільність, волога*

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