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Effect of Nutrient Substrate on Seedling Growth and Biomass Allocation of *Picea obovata* Ledeb. in Northern Mongolia

Damdinjamts Jagdag*[1]*, Postgraduate Student;
ORCID: https://orcid.org/0000-0002-9237-7627
Ganbaatar Batsaikhan*[2]*, Candidate of Agriculture, Assoc. Prof.;
ORCID: https://orcid.org/0000-0001-7752-2286
Nachin Baatarbileg*[1]*, Candidate of Agriculture, Prof.;
ORCID: https://orcid.org/0000-0002-3489-1257
Anatoly I. Lobanov*[3]✉*, Candidate of Biology, Senior Research Scientist;
ResearcherID: ABB-8764-2020, ORCID: https://orcid.org/0000-0003-0505-8212
Sukhbaatar Gerelbaatar*[4]*, Candidate of Biology, Prof.; *ResearcherID: AAK-4597-2021, ORCID: https://orcid.org/0000-0002-9561-5256*
[1]Institute of Forestry Science of the National University of Mongolia, ul. Universitetskaya, 1, Ulaanbaatar, 14201, Mongolia; jagdag_0301@yahoo.com, baatarbileg@num.edu.mn
[2]Institute of Geography and Geoecology of the Mongolian Academy of Sciences, ul. Baruun Selbe, 15, Ulaanbaatar, 15170, Mongolia; batlaa_85@yahoo.com
[3]Scientific Research Institute of Agrarian Problems of Khakassia, ul. Sadovaya, 5, Zelenoe village, Republic of Khakassia, 655132, Russian Federation; anatoly-lobanov@ksc.krasn.ru✉
[4]School of Engineering and Technology, National University of Mongolia, ul. Universitetskaya, 3, Ulaanbaatar, 14201, Mongolia; gerelbaatar@seas.num.edu.mn

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Abstract. The development of seedling production technology and methods of establishing high-yielding plantations of *Picea obovata* Ledeb. on a scientific basis is one of the urgent problems of forestry in Mongolia. In this study, we aimed to solve the following problems: to conduct a comparative analysis of the seedling growth parameters and biomass accumulation grown on different nutrient substrates; to assess the relationship between seedling growth, biomass accumulation and soil properties; to determine the most optimal nutrient substrates for seedling production of Siberian spruce in greenhouse conditions in Northern Mongolia. Six formulations of nutrient substrates (T1, T2, T3, T4, T5, T6) were used for the seedling production of *Picea obovata* Ledeb. in greenhouses equipped with a sprinkler system. Nutrient substrates were prepared using black soil, manure, compost, peat, sawdust, sand in different composition ratios. During the 4-year-observation period height, root collar diameter, root length and aboveground and belowground biomass of seedlings were measured at the end of each growing season. We divided the biomass of seedlings into several structural elements. We found that all tested nutrient substrates, except the control substrate, had a positive effect on seedling growth in height and diameter. Comparative analyses showed that different ratio and composition of black soil, compost, manure, sawdust, and sand in the nutrient substrate had different effects on seedling growth ($p > 0.001$) and biomass accumulation ($p > 0.001$). Among the proposed nutrient substrates, the treatments T2 (50 % black soil + 20 % sand + 20 % peat + 10 % compost) and T6 (60 % black soil + 20 % sand + 10 % peat + 10 % compost) were selected as the most effective soil substrate that are suitable for further seedling production of Siberian spruce under greenhouse

conditions in Mongolia. There fore, it was observed that good root system development was a determinant of seedling growth in height, diameter, and aboveground biomass accumulation especially from 3–4 years of age. Spruce seedling growth was positively correlated not only with humus content (r = 0.46), but also with soil acidity (r = 0.43) and available phosphorus (r = 0.48). The results of this investigation made an important contribution to the development of production technology for growing standard and large-sized seedlings of *Picea obovata* in greenhouse complexes in Northern Mongolia.
Keywords: biomass, height, diameter, Siberian spruce, Northern Mongolia, nutrient substrate, growth, greenhouse

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Научная статья

Влияние питательного субстрата на рост и распределение биомассы сеянцев *Picea obovata* Ledeb. в Северной Монголии

***Д. Жагдаг[1]**, аспирант; ORCID: https://orcid.org/0000-0002-9237-7627*
***Г. Батсайхан[2]**, канд. с.-х. наук, доц.; ORCID: https://orcid.org/0000-0001-7752-2286*
***Н. Баатарбилэг[1]**, канд. с.-х. наук, проф.;*
ORCID: https://orcid.org/0000-0002-3489-1257
***А.И. Лобанов[3]✉**, канд. биол. наук, ст. науч. сотр.; ResearcherID: ABB-8764-2020,*
ORCID: https://orcid.org/0000-0003-0505-8212
***С. Гэрэлбаатар[4]**, канд. биол. наук, проф.; ResearcherID: AAK-4597-2021,*
ORCID: https://orcid.org/0000-0002-9561-5256

[1]Институт лесоведения Монгольского государственного университета, ул. Университетская, д. 1, Улан-Батор, Монголия, 14201; jagdag_0301@yahoo.com, baatarbileg@num.edu.mn

[2]Институт географии и геоэкологии Монгольской академии наук, ул. Баруун сэльбэ, д. 15, Улан-Батор, Монголия, 15170; batlaa_85@yahoo.com

[3]Научно-исследовательский институт аграрных проблем Хакасии – филиал ФИЦ КНЦ СО РАН, ул. Садовая, д. 5, с. Зеленое, Республика Хакасия, Россия, 655132; anatoly-lobanov@ksc.krasn.ru✉

[4]Монгольский государственный университет, ул. Университетская, д. 3, Улан-Батор, Монголия, 14201; gerelbaatar@seas.num.edu.mn

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Аннотация. Разработка технологии производства сеянцев и способов создания высокопродуктивных насаждений *Picea obovata* Ledeb. на научной основе является одной из актуальных проблем лесного хозяйства Монголии. Проведен сравнительный анализ показателей роста выращенных на различных питательных субстратах сеянцев ели сибирской и накопления их биомассы. Оценена взаимосвязь между ростом сеянцев, накоплением их биомассы и свойствами почвы. Определены наиболее оптимальные питательные субстраты для выращивания сеянцев в тепличных условиях Северной Монголии. Сеянцы ели сибирской выращивали в теплицах, оборудованных системой дождевания. Применяли 6 видов питательных субстратов: Т1, Т2, Т3, Т4, Т5, Т6. Питательные субстраты готовили с использованием чернозема, навоза, компоста, торфа, опилок и песка в различных соотношениях. В течение 4-летнего периода наблюдений в конце каждого вегетационного периода измеряли высоту, диаметр корневой шейки, длину корня и определяли надземную и подземную биомассу сеянцев. Биомасса сеянцев разделена на несколько структурных элементов. Установлено, что все испытанные питательные субстраты, за исключением контрольного (Т1), оказали положительное влияние на рост сеянцев в высоту и по диаметру. Сравнительный анализ показал, что различные соотношение и состав чернозема, компоста, навоза, опилок и песка в питательном субстрате по-разному влияют на рост сеянцев ($p > 0,001$) и накопление биомассы ($p > 0,001$). Питательные субстраты Т2 (50 % чернозема + 20 % песка + 20 % торфа + + 10 % компоста) и Т6 (60 % чернозема + 20 % песка + 10 % торфа + 10 % компоста) оказались наиболее эффективными, подходящими для дальнейшего производства сеянцев ели сибирской в тепличных условиях Монголии. Отмечено, что хорошее развитие корневой системы было определяющим фактором роста сеянцев в высоту, по диаметру и накопления надземной биомассы, особенно с 3–4-летнего возраста. Рост сеянцев ели положительно коррелировал не только с содержанием гумуса ($r = 0,46$), но и с кислотностью почвы ($r = 0,43$) и доступным фосфором ($r = 0,48$). Результаты этих оценок являются важным вкладом в разработку технологии выращивания стандартных и крупномерных сеянцев *P. obovata* в тепличных комплексах Северной Монголии.

Ключевые слова: биомасса, высота, диаметр, ель сибирская, Северная Монголия, питательный субстрат, прирост, теплица

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Introduction

Forests in Mongolia play an important role in sustainable socio-economic development of the country, ensuring its economic, energy, environmental and food security [2, 42]. They become not only a source of valuable wood resources, but also perform the number of environmental and ecosystem functions, provide ecosystem services to the population, maintain water balance and protect soils from erosion, and conserve biodiversity [1, 35].

Picea obovata Ledeb. in the boreal zone of Russia and Mongolia is one of the main forest-forming tree species of woody plants that geographically distributed from the north of the European part of Russia to the Pacific coast that dominates in dark coniferous forests [22, 39, 44].

Spruce forests in Mongolia basically grow in the northern part of the country coinciding with the distribution of seasonal permafrost soils. However, they mainly grow on the north-facing slopes of the mountains, and along the valleys of small rivers, forming pure and mixed stands. Spruce stands show better growth on loamy, well-drained, and sandy soils [4, 28, 43].

According to statistics [7] a total of 21.1 thousand ha of spruce forests are registered in Mongolia, which occupy only 0.18 % of the country's forest cover. In recent decades, degradation and deforestation of natural spruce forests caused by global warming and unsustainable forest management indicate the importance of intensified forestry measures in these forests. They should be aimed at successful natural regeneration and artificial restoration of these forests using high-quality seedlings produced in the forest nurseries [12, 16].

A number of studies emphasize that success of reforestation depends not only on the site quality and post-planting stress of transplanted seedlings [11, 13, 37], but also on the quality of the seedlings themselves [8, 27, 32, 47] used for planting. Therefore, the size of seedlings and their root system play an important role in plant survival [6, 14, 37, 45, 46].

Several researchers [10, 26, 36] noted that well-developed root systems allow seedlings to overcome transplanting stress, which is usually associated with water deficit [38], and they are able to penetrate the soil faster to use the water and nutrients they need.

Previous studies [3, 5, 6, 21, 28, 32, 33, 40] were basically devoted to the development of seedling production technology and the population ecology of Siberian spruce plantations in the Northern and Eastern Kazakhstan and Central Siberia. It is well-known that Redko et al. [44] developed the bioecological basis for the seedling production of spruce in forest nurseries of the Leningrad region, Russia. Such researches there fore were carried out in Northern Mongolia [15, 16]. Some studies emphasized that the use of various fertilizers and growth stimulants [19, 20, 45] had a positive effect on seedling growth of coniferous tree species.

A number of researchers [21, 22, 29] emphasized that the use of various fertilizers and growth stimulants had a positive effect on the growth of seedlings of coniferous trees. Comparative growth analyses of seedling growth for Siberian spruce planted in greenhouse conditions on various soil substrates consisting of soil, humus, peat, sawdust, and sand in Northern and Eastern Kazakhstan were carried out. However, the comparative assessment on individual seedling growth performance, biomass accumulation and morphological parameters of Siberian spruce in relation to different nutrient substrates under the conditions of Mongolia has not been previously studied.

In this study, we purposed to detect different effects of nutrient substrates from organic origin on growth, development, and biomass accumulation of seedlings of *Picea obovata* in greenhouse conditions of Northern Mongolia.

The aim of this study was to 1) conduct a comparative analyses of seedling growth performance and biomass accumulation in relation to different nutrient substrates, 2) assess the relationships between seedling growth and soil properties, 3) select the most optimal nutrient substrate for seedling production of *Picea obovata* in the greenhouse conditions of Northern Mongolia.

Research objects and methods

Characteristics of the study area. This study was carried out on an experimental forest nursery (47º59' N, 106º57' E) established on loamy black soils, which formed on alluvial deposits. According to Forest-vegetation zoning [30], the study area belongs to the East Khentii province of the South-Transbaikalia Forest – vegetation zone. The climate in the study area is sharply continental: the annual mean air temperature is –3.5 °C, and annual rainfall is 240 mm, 89.2 % of the rainfall falls during the vegetation season, which lasts 125 days a year [34]. The soils in the study area are mainly represented by seasonally frozen black soil and urbanozem [18, 25].

Preparation of different nutrient substrates. Organic substances readily available in the study area were used for the preparation of different nutrient substrates. For a comparative assessment and preparation of different soil treatments, we used black soil, sand, sawdust, peat, manure, and compost in different proportions. Therefore, we used compost originated from cow manure and plant waste to increase organic matter in the nutrient substrate.

The soil chemical properties were determined using well-known methods of soil analyses [13–16].

The content of chemical elements in nutrient substrates was determined according to OST 56-98–93. Here we determined alkaline-hydrolysable nitrogen and pH according to Kornfild M. GOST 26483–85, TSINAO and GOST 27784–88. Content of available phosphorus, potassium and ash content was determined according to Kirsanov.

Experimental design and statistical analyses. Experimental planting was carried out in greenhouses equipped with a sprinkler system using high quality and stratified seeds of *Picea obovata*, collected from natural spruce stands distributed in the Western Khentii mountains. Seed sowing was conducted in the first decade of 2018, when the soil temperature exceeded 9 °C at the topsoil. In accordance with recommendation of scientists [9], the seeds were sown to a depth of 0.6 cm, and then mulched with a thin layer (1.0–1.5 cm) of sawdust.

Agrotechnical measures including irrigation (6–10 l/m^2 or 60–100 $m^3 \cdot ha^{-1}$), weeding and soil loosening were performed annually as needed.

To monitor the growing environment interior greenhouses, the temperature and humidity of the air and soil were continuously measured. The air and soil temperature were measured with mercury and Savinov thermometer, respectively. The daily course of air temperature was recorded by M-16A thermographs, the relative air humidity was determined by aspiration psychrometers MV-4M, and its daily course by M-21A hygrographs.

The morphological parameters (stem height, root neck diameter, length of tap and lateral roots) and biomass (needle, stem, root biomass) were determined annually at the third decade of September from 2018 to 2021 on 83–84 individuals from each treatment to compare the effects of different soil substrates on growth and root development of seedlings.

The stem height and root collar diameter were measured using a metal ruler and an Electronic Digital Caliper – G06064731 with an accuracy of 0.1 cm and 0.1 mm, respectively. To determine the biomass of seedlings, the roots were separated from the soils and washed. The entire biomass of seedlings was divided into stem, needle, tap and lateral roots, and oven-dried in an oven at 75 °C for 72 hours to constant weight. Fresh and dry biomass was weighted using electronic balance (ML 02-11) with an accuracy of 0.001 g.

Statistical analyses were performed using Microsoft Excel and One-Way Analyses of Variance. The Pearson correlation coefficient was used to reflect the linear correlation of independent variables, as well as the Duncan multiple range test (DMRT) was used to measure specific differences between pairs of means and select the most optimal experimental treatments.

Results and discussion

Main chemical properties and component of nutrient substrates for experimental planting of spruce seedlings were illustrated in the previously published article Jagdag et al. [6] using following abbreviations of components: BS – black soil; S – sand; SD – sawdust; C – compost; M – manure; P – peat. In nutrient substrate T1 treatment consists of only BS(100). Therefore, T2, T3, T4 and T5 treatments had following compositions as BS(50)S(20)P(20)C(10), BS(50)S(20)SD(20)M(10), BS(40)S(20)SD(20)M(20), DS(30)S(20)SD(30)M(20) and DS(60)S(20)P(10)C(10), respectively. Here, the percentage of each component in the nutrient substrate is indicated in parentheses.

Jagdag et al. [16] reported that all these nutrient substrates showed a weak alkalinity, close to neutral, and a fairy high nutrient content, and T2 and T6 treatments contained the highest amount of nutrients compared to the control (T1).

Growth performance of seedlings in different nutrient treatments. In our study, successful seed germination was observed in soils with temperatures ranging from 18 to 28 °C. Meanwhile, we also found a high variation in height ($p > 0.001$), root collar diameter ($p > 0.001$) for seedlings of Siberian spruce in relation to different soil properties and is tended to increase with age [16].

The fastest growth in height and diameter was observed in T6 and T2 treatments, where the ratio of black soil, sand, peat and compost in nutrient substrates was 6:2:1:1 and 5:2:2:1, respectively (Fig. 1 *a*, *b*).

Meanwhile, a slower growth of seedlings was recorded on T1 (only black soil) and T5 (30 % black soil + 20 % sand + 30 % sawdust + 20 % manure) treatments. In addition, such a weak growth and poor development of the root systems can be associated with a rather high content of undecomposed and semi-decomposed organic substances.

According to Duncan's multiple tests, the fastest growth in the length of the taproots and the number of lateral roots were recorded in T6 and T2 treatments, where the ratio of the volumes of black soil, sand, peat and compost in soil substrates was 6:2:1:1 and 5:2:2:1, respectively (Fig. 1 *c*, *d*, *e*).

At the age of 3 years seedlings growing on T1 soil substrates reached their standard sizes (stem height 10 cm; root neck diameter 2 mm). For example, seedling height and root neck diameter for seedlings, growing on T2 and T6 was exceeded by 22.8 and 14.1 % compared to standard size, respectively [16].

The experience from other studies [28, 31] suggests using the large-sized 4 years-old seedlings of Siberian spruce to establishment the forest plantations, which allows to significantly reduce silvicultural measures associated with post-planting survival and seedling growth.

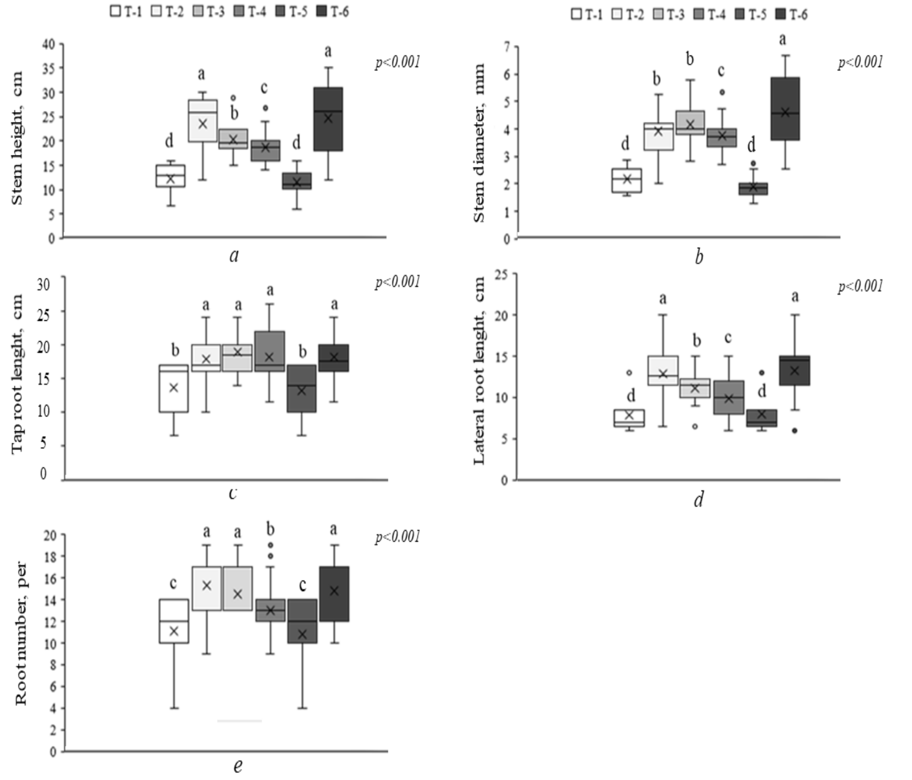

Fig. 1. Comparison of the biometric parameters of *Picea obovata*, grown on different nutrient substrates. Differences between pairs of mean values according to Duncan: *a* – maximum value; *d* – minimum value; *b*, *c* – transitional values between *a* and *d*

In our study, T2 and T6 nutrient substrates had a greater positive effect on seedling growth and biomass accumulation among treatments. In comparison, seedlings growing on these soil substrates showed 2 times faster growth in height (91.9 and 100 %) and diameter (77.3 and 109.1 %) compared to control treatment [6]. Overall, all these substrates resulted a better seedling growth compared to control treatments in our study. It can be concluded that the adding organic substances such as sawdust, peat, manure, and compost significantly improves not only the soil nutrient regime, but also its physical properties, including aeration and water-holding capacity of the soils.

Accumulation and distribution of biomass by their structural components. We found a high variation in aboveground and belowground biomass accumulation ($p > 0.001$), which is caused by seedling age and nutrient properties. The dynamics of the aboveground and belowground biomass accumulation of seedlings over the observation period is presented in Table 1.

In terms of biomass accumulation, during the first 2 years a relatively faster biomass production of above-ground part than of belowground part was observed (Table 1).

Table 1

Accumulation of above- and belowground biomass of spruce seedlings over a 4-year observation period

Treatment	Number of samples	Seedling age, year					
		2		3		4	
		AGB	BGB	AGB	BGB	AGB	BGB
T1	250	0.042± ±0.038 (100)	0.025± ±0.024 (100)	0.355± ±0.222 (100)	0.150± ±0.113 (100)	2.182± ±0.377 (100)	0.736± ±0.088 (100)
T2	250	0.046± ±0.041 (109.5)	0.028± ±0.024 (112)	0.411± ±0.231 (115)	0.174± ±0.115 (116)	4.391± ±1.587 (201.2)	1.312± ±0.413 (178.3)
T3	250	0.042± ±0.038 (100)	0.025± ±0.024 (100)	0.356± ±0.222 (100.3)	0.151± ±0.113 (100.7)	4.004± ±0.846 (183.5)	1.105± ±0.258 (150.1)
T4	250	0.042± ±0.038 (100)	0.025± ±0.024 (100)	0.353± ±0.222 (99.4)	0.144± ±0.113 (96)	3.301± ±0.981 (151.3)	0.954± ±0.243 (129.6)
T5	250	0.045± ±0.039 (107)	0.025± ±0.024 (100)	0.350± ±0.222 (98.6)	0.150± ±0.113 (100)	2.146± ±0.389 (98.3)	0.726± ±0.094 (98.6)
T6	250	0.050± ±0.042 (119)	0.030± ±0.025 (120)	0.418± ±0.232 (117.8)	0.179± ±0.116 (119.3)	4.398± ±1.697 (201.6)	1.342± ±0.439 (182.3)

Note: AGB – aboveground biomass, g; BGB – belowground biomass, g. The denominator (in parenthesis) indicates % relative to the control.

A similar picture was reported by Siberian scientists from the studies in southern taiga of the Krasnoyarsk territory [20]. Since the age of 3 and 4, there was observed an accelerated growth and predominance of aboveground biomass in total biomass. In above- and belowground ratio, we found that percentage of aboveground biomass tended to increase with seedling ages (Table 2).

Table 2

Dynamics of root/shoot ratio in different ages of spruce seedlings

Treatment	Seedling age, year		
	2	3	4
T1	0.59	0.42	0.33
T2	0.60	0.42	0.30
T3	0.59	0.42	0.28
T4	0.59	0.40	0.29
T5	0.56	0.43	0.34
T6	0.60	0.42	0.31

Among these substrates the greatest positive and statistically significant effect on biomass accumulation of seedlings (*Picea obovata*) belonged to the nutrient substrates, where compositions were 6:2:1:1 (T2) and 5:2:2:1 (T6), respectively (Fig. 2).

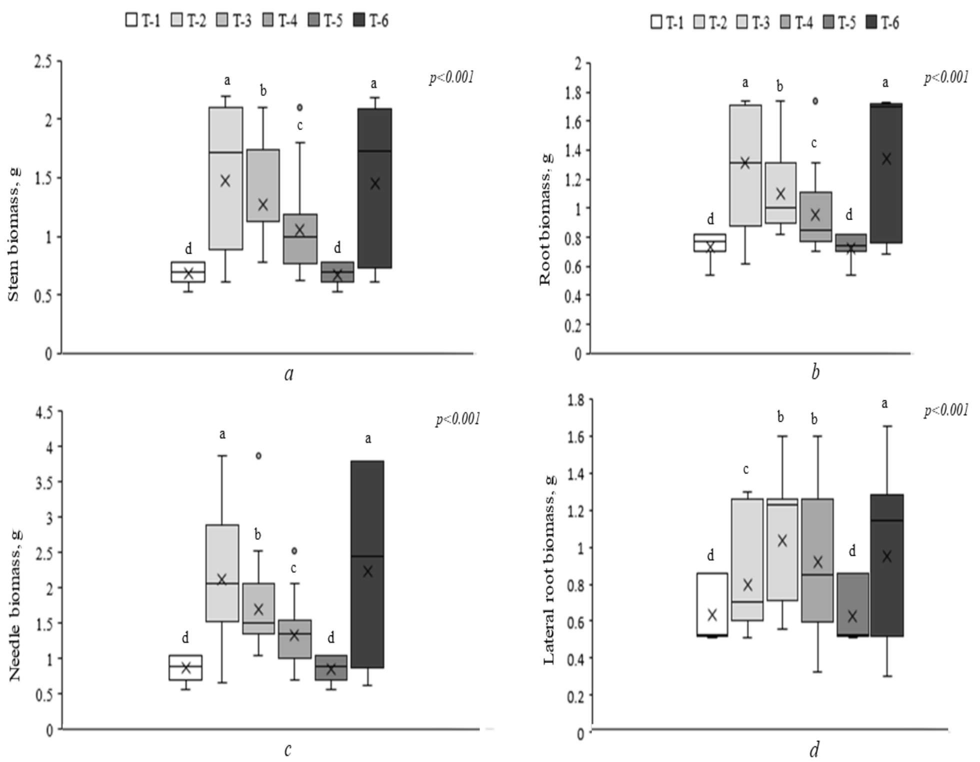

Fig. 2. Distribution of the biomass of seedlings by structural components grown on various nutrient substrates

Relationships between growth and soil properties. The correlation matrix between morphological and soil chemical properties for seedlings of Siberian spruce is illustrated in Table 3.

Table 3

Correlation matrix between morphological and nutrient chemical properties for seedlings of Siberian spruce

Variables	Height, cm	Diameter, mm	Number of roots, pcs	Main root length, cm	Biomass, g			pH	Humus, %	P_2O_5	K_2O
					stem	root	needle				
Height, cm	1										
Diameter, mm	0.952	1									
Number of roots, pcs	0.954	0.938	1								
Main root length, cm	0.867	0.963	0.908	1							
Stem biomass, g	0.979	0.939	0.993	0.888	1						
Root biomass, g	0.985	0.910	0.970	0.824	0.990	1					
Needle biomass, g	0.961	0.871	0.864	0.722	0.909	0.950	1				
pH	–0.335	–0.278	–0.413	–0.138	–0.389	0.432	0.450	1			
Humus, %	–0.334	0.461	–0.209	0.466	–0.217	–0.186	–0.244	–0.426	1		
P_2O_5	0.119	0.328	0.350	0.479	0.259	0.149	–0.020	–0.305	0.189	1	
K_2O	–0.045	0.033	0.143	0.051	0.080	0.050	–0.013	–0.723	0.644	0.694	1

Table 3 showed that the growth of spruce seedlings positively correlated with not only to humus content (r = 0.46), but also with nutrient acidity (r = 0.43) and available phosphorus (r = 0.48). Furthermore, correlation matrix demonstrated that seedling growth strongly dependent on development of the root system and its biomass accumulation.

Conclusion

The production of standard and large-sized Siberian spruce seedlings under typical conditions is the most effective way to meet the existing need for high-quality planting material for the restoration of spruce forests in Northern Mongolia. It is shown that the different ratio and composition of nutrient substrates consisting of black soil with the addition of sand, peat and compost have different effects on the growth of seedlings ($p > 0.001$) and biomass accumulation ($p > 0.001$). Meanwhile, the growth of spruce seedlings positively correlated not only with humus content (r = 0.46), but also with soil acidity (r = 0.43) and available phosphorus (r = 0.48). Among tested soil substrates the treatments T2 (50 % black soil + 20 % sand + 20 % peat + 10 % compost) and T6 (60 % black soil + 20 % sand + 10 % peat + 10 % compost) were selected as the most effective soil substrate that suitable (improved nutrients and aeration) for further seedling production of Siberian spruce. These selected nutrient substrates are recommended for mass production of *Picea obovata* Ledeb. seedling in greenhouse conditions of Northern Mongolia. The results of the research can be used to develop an industry standard for seedlings and seedlings of coniferous species for Northern Mongolia.

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