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ХВОЙНЫЕ БОРЕАЛЬНОЙ ЗОНЫ

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ВЛИЯНИЕ УСЛОВИЙ ПРОИЗРАСТАНИЯ СОСНЫ КЕДРОВОЙ СИБИРСКОЙ (PINUS SIBIRICA DU TOUR) НА ПРОЦЕССЫ ФОТОСИНТЕЗА И ТРАНСПИРАЦИИ

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Исследовали влияние условий произрастания сосны кедровой сибирской (Pinus sibirica Du Tour) на процессы фотосинтеза и транспирации. Выявили прямую зависимость между уменьшением интенсивности света и снижением скорости фотосинтеза, и обратную зависимость между уменьшением интенсивности света и скоростью транспирации у образцов, произрастающих в фитотроне. У образцов, произрастающих в естественных условиях, выявлена параболическая зависимость между интенсивностью света и скоростью фотосинтеза и транспирации. При изучении влияния содержания CO_2 *в воздухе на скорость фотосинтеза у всех образцов наблюдается прямая зависимость: при снижении содержания* CO_2 *в воздухе отмечается снижение скорости фотосинтеза, при повышении содержания* CO_2 *наблюдается увеличение скорости фотосинтеза. При исследовании изменения скорости транспирации от содержания* CO_2 *четкой зависимости не выявлено.*

Ключевые слова: *сосна кедровая сибирская, фотосинтез, транспирация, интенсивность света, содержание* CO_2.

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INFLUENCE OF THE GROWING CONDITIONS OF SIBERIAN CEDAR PINE (PINUS SIBIRICA) ON THE PROCESSES OF PHOTOSYNTHESIS AND TRANSPIRATION

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The influence of the growing conditions of Siberian cedar pine (Pinus sibirica) on the processes of photosynthesis and transpiration was investigated. A direct relationship was revealed between a decrease in light intensity and a decrease in the rate of photosynthesis, and an inverse relationship between a decrease in light intensity and the rate of transpiration in samples growing in phytotron. A parabolic relationship between the intensity of light and the rate of photosynthesis and transpiration was revealed in samples growing in natural conditions. When studying the effect of the CO_2 *content in the air on the photosynthesis rate, a direct relationship is observed in all samples: with a decrease in the* CO_2 *content in the air, a decrease in the photosynthesis rate is observed, with an increase in the* CO_2 *content, an increase in the photosynthesis rate is observed. The study of the change in the transpiration rate from the* CO_2 *content did not reveal a clear dependence.*

Keywords: *Siberian cedar pine, photosynthesis, transpiration, light intensity,* CO_2 *content.*

INTRODUCTION

Research on Siberian cedar pine *(Pinus sibirica Du Tour)* has been conducted since the mid-20th century (Bobrov, 1982; Putenikhina & Putenikhin, 2015). Numerous studies have been carried out in Siberia and the Urals (Mashtakov, 2016; Andreeva, Terekhov et al., 2019; Ryl, 2020).

R.N. Matveeva, O.F. Butorova, and N.P. Bratilova (2001, 2007, 2014, 2020, 2021, 2022) had conducted long-term studies on Siberian cedar pine in the Krasnoyarsk Krai since the 1960s. Their research focused on biomass structure, yield, growth characteristics and variability of seedlings and trees of different ages.

Studies on the introduction of Siberian cedar pine (*Pinus sibirica Du Tour*) to the European part of Russia had also been conducted. These studies took place in the Moscow Region (Belinsky, 2015), Voronezh Region (Levin, 2021), and Vologda Region (Khamitov & Khamitova, 2013; Khamitov, Babich & Drozdov, 2016). Characteristics of seed and planting material, germination and survival ability in the conditions of introduction were mainly studied.

Photosynthesis and transpiration in coniferous tree species had been studied by researchers such as S.N. Senkina (2009) and A.V. Sokolov & V.K. Bolondinsky (2020). S.N. Senkina presented the results of long-term research on transpiration and stomatal resistance of Scots pine needles in growing stocks of various compositions. Seasonal and daily dynamics of these parameters, as well as their variations depending on the age of the needles and their position within the tree crown, were described. A.V. Sokolov and V.K. Bolondinsky modeled stomatal, mesophyll, and biochemical regulation of photosynthesis in Scots pine based on experimental data. Using the developed model, they calculated CO_2 assimilation by forest ecosystems and evaluated water use efficiency (WUE) of plants.

O.G. Bender (2019) analyzed the seasonal dynamics of the photosynthetic apparatus and water exchange characteristics in vegetative progeny of Siberian stone pine (*Pinus sibirica Du Tour*) and dwarf Siberian pine (*Pinus pumila (Pall.) Regel*) in southern Western Siberia. Species and seasonal traits in the content of photosynthetic pigments, chlorophyll fluorescence parameters, and free and bound water content in snow-covered and above-snow needles were identified. Bender demonstrated the higher plasticity of Siberian cedar pine in adapting to low winter temperatures.

Additionally, O.G. Bender (2017) studied the photosynthetic activity of Siberian cedar pine needles at the northern limit of the species' range. He concluded that photosynthesis in Pinus sibirica needles actively occurs under low photosynthetically active radiation (PAR). An increase in temperature caused a significant decline in CO_2 uptake. Since the temperature optimum of plant photosynthesis is genetically determined, it can be assumed that climate warming will negatively affect northern populations of Pinus sibirica, leading to a decrease in photosynthesis intensity and productivity of native cedar forests.

No studies have examined the effect of growth conditions on photosynthesis and transpiration rates of Siberian cedar pine (*Pinus sibirica Du Tour*) in the Moscow Region. This research is therefore timely and relevant.

The objective is to investigate the influence of growth conditions on the processes of photosynthesis and transpiration in Siberian cedar pine (*Pinus sibirica Du Tour*).

The tasks are:

– to determine the rates of photosynthesis and transpiration in Siberian cedar pine seedlings (*Pinus sibirica Du Tour*) grown under natural climatic conditions, with varying light intensity and CO_2 concentrations;

– to determine the rates of photosynthesis and transpiration in Siberian cedar pine seedlings (*Pinus sibirica Du Tour*) grown in phytotron conditions, with varying light intensity and CO_2 concentrations.

MATERIALS AND METHODS OF RESEARCH

The object of this study is five-year-old seedlings of Siberian cedar pine.

Siberian cedar pine, or Siberian pine (*Pinus sibirica Du Tour*), is a tree belonging to the family *Pinaceae*. It is a first-class forest-forming species, capable of reaching 40–50 meters in height and 1.5–2 meters in diameter (Smolonogov & Zalesov, 2002).

In natural conditions, mature trees typically have a large, spreading oval or conical crown. The needles are grouped in bundles of five and grow on brachyblasts. The needles are dark green, dense, and range from 5 to 13 cm in length and 0.8–1.2 mm in width. In cross-section, they have a triangular shape.

The extensive, densely foliated crowns and the color of the needles indicate the shade tolerance of this species. Siberian cedar pine is one of the slowest-growing forest-forming species but adapts well to shaded conditions in its young age. Experimental studies have shown that seedlings grow better with 20 % shading. However, with more intense shading, a decline in growth processes and chlorophyll efficiency is observed (Babich, Khamitov & Khamitova, 2014).

The intensity of photosynthesis is significantly influenced by the factors such as light, temperature, soil moisture, CO_2 concentration in the air, the supply of mineral nutrients, and other external conditions. Some factors, such as light and CO_2 availability, have a direct impact on photosynthesis. Others, like water and nutrient content in the soil, often act indirectly by influencing other physiological processes.

For most plants, the direct correlation between photosynthesis intensity and light intensity is observed only at relatively low light levels. As light intensity increases, the rate of photosynthesis growth slows down, eventually reaching a plateau. This state, referred to as light saturation, indicates that photosynthesis at this point is more dependent on other factors than light intensity.

Many factors can influence the rate of photosynthesis in winter evergreen plants. The lower light availability and colder temperatures in winter are limiting factors for photosynthesis. Additionally, plant health, age, and flowering condition can also alter the rate of this process.

Carbon dioxide is essential as a carbon source for the production of sugars and other organic compounds. The more CO_2 available, the faster photosynthetic reactions occur. However, when the stomata in pine needles open to allow the uptake of CO_2, water is inevitably lost through these pores in the form of vapor.

Since pines retain their needles year-round, they are capable of photosynthesis during the winter months. This provides a significant advantage over deciduous trees that lose their leaves. However, pine needles have a small surface area, which limits the amount of solar energy they can capture for this process.

Under freezing conditions, ice may form between the cells of winter evergreen trees, leading to dehydration. During winter dehydration, the stomata may close to reduce water loss, although this also halts gas exchange and further restricts photosynthesis.

EXPERIMENTAL PART

Five-year-old seedlings of Siberian cedar pine (*Pinus sibirica Du Tour*) grown in the Moscow Region were used for the study. The first group of seedlings (30 specimens) was grown under natural climatic conditions in pots (Fig. 1*a*), meaning they were exposed to sub-zero air temperatures and covered with snow. The second group of seedlings (30 specimens) was grown in a phytotron, where the air temperature was above 0 °C, and there was no snow cover (Fig. 1*b*).

The morphometric parameters of Siberian cedar pine (*Pinus sibirica Du Tour*) specimens grown under different conditions are presented in the table.

a *b*

Figure 1. Siberian cedar pine (*Pinus sibiricaDu Tour*) seedlings grown:
a – under natural conditions; *b* – in a phytotron

Morphometric parameters of Siberian cedar pine (Pinus sibirica Du Tour) specimens

Sample number	Seedlings growing in phytotron		Seedlings growing in natural conditions	
	seedling height, cm	length of needles, cm	seedling height, cm	length of needles, cm
1	6,7	32,3	6,2	31,1
2	7,0	35,5	6,4	30,5
3	6,8	30,3	9,3	32,6
4	13,4	38,4	5,6	33,4
5	7,5	36,8	6,4	35,4
6	8,9	37,7	7,6	36,5
7	7,2	31,4	7,1	32,4
8	10,2	42,1	8,3	33,9
9	7,6	36,6	6,4	34,4
10	6,4	36,4	6,5	35,6
11	7,0	35,4	6,9	31,7
12	8,5	35,3	7,4	36,1
13	6,0	32,3	5,3	32,5
14	7,8	34,4	5,8	32,5
15	8,4	33,4	6,3	31,3
16	7,7	32,1	8,2	37,1
17	8,2	31,9	5,9	35,6
18	10,5	35,5	7,6	35,8
19	7,2	34,4	7,2	37,8
20	7,6	37,3	8,4	38,6
21	7,8	36,6	6,8	35,4
22	7,6	36,3	6,5	34,6

End of the table

Sample number	Seedlings growing in phytotron		Seedlings growing in natural conditions	
	seedling height, cm	length of needles, cm	seedling height, cm	length of needles, cm
23	8,2	37,4	7,4	34,5
24	9,8	34,5	6,9	33,5
25	7,6	35,4	7,4	33,4
26	9,2	31,6	6,1	33,1
27	9,0	40,1	5,4	34,5
28	8,8	35,2	6,2	32,1
29	8,5	38,5	5,9	31,5
30	7,5	36,4	6,7	36,6
Average values	8,2±1,4	35,5±2,5	6,8±0,9	34,1±2,1

The study was conducted in March 2022. The climate of the study area is humid, moderately continental, with strong influence from the Atlantic Ocean, and distinct seasonality. The average annual air temperature is +7.1 ºC. The winter is moderately cold with thaws, and the air temperature fluctuates between –5 ºC and –20 ºC. The snow cover is stable and usually does not exceed 60 cm.

Photosynthesis processes were studied using a portable plant gas exchange measurement system, model LI-6800, LI-COR. This system has unparalleled capabilities for studying plant gas exchange and chlorophyll fluorescence (Evans & Santiago, 2014; Coursolle et al., 2019; Riches & Farmer, 2020).

The net assimilation rate A (photosynthesis) (μmol m^{-2} s^{-1}) and transpiration rate E (mol m^{-2} s^{-1}) were determined depending on light intensity (Q) and CO_2 concentration (Ci). When measuring the dependence of photosynthesis and transpiration rates on light intensity, the CO_2 flow rate in the leaf chamber was 400 μmol/s, and its concentration was 400 μmol/mol. At this point, light intensity was decreased from 1500 to 0 μmol m^{-2} s^{-1}.

Next, measurements were taken to assess the dependence of transpiration and photosynthesis rates on the CO_2 content in the air. To do this, the CO_2 content in the chamber was gradually decreased from 400 to 0 mmol/mol^{-1}, then increased to 1200 mmol/mol^{-1}, and reduced again to 400 mmol/mol^{-1}. A CO_2 concentration of 400 mmol/mol^{-1} corresponds to the ambient CO_2 level. The following sequence of CO_2 values was used: 400, 300, 200, 100, 50, 0, 250, 400, 600, 800, 1000, 1200, 900, 500, 400 mmol/mol^{-1}.

RESULTS AND DISCUSSION

The results of the study were analyzed using graphs.

When studying photosynthesis in the samples that grew in the phytotron, a dependence was identified: as light intensity decreased, the rate of photosynthesis decreased, and the rate of transpiration increased. This correlation was found in 27 samples, which showed the greatest growth and needle size (Figure 2).

The remaining 3 samples, grown in the phytotron, exhibited smaller sizes and yellowing needles. A different pattern was observed in these samples: as light intensity decreased to 150 mmol m^{-2} s^{-1}, both photosynthesis and transpiration rates decreased. Then, as light intensity decreased to 0 mmol m^{-2} s^{-1}, both transpiration and photosynthesis rates increased (Figure 3).

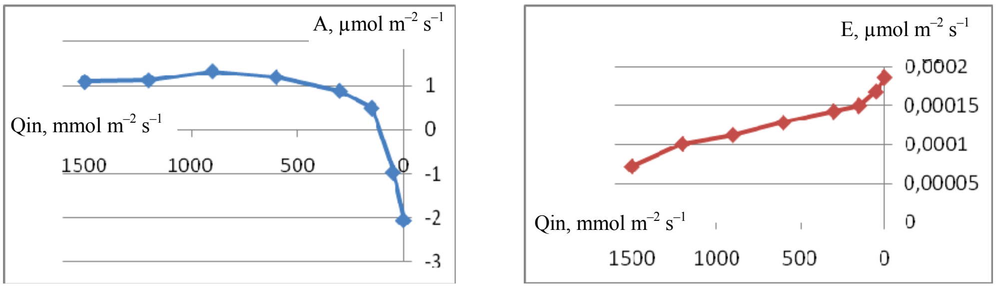
The study of the correlation between photosynthesis and transpiration rates and light intensity in the samples grown under natural conditions showed that in most seedlings (24 samples), as light intensity decreased to 1000 mmol m^{-2} s^{-1}, photosynthesis and transpiration rates increased. After that, as light intensity decreased to 300, the rates of photosynthesis and transpiration leveled off. Finally, as light intensity decreased to 0 mmol m^{-2} s^{-1}, both photosynthesis and transpiration rates dropped (Figure 4).

In 6 samples grown under natural conditions, a direct linear dependence was observed: as light intensity decreased, the rates of photosynthesis and transpiration also decreased (Figure 5). These samples exhibited yellowing needles and smaller sizes.

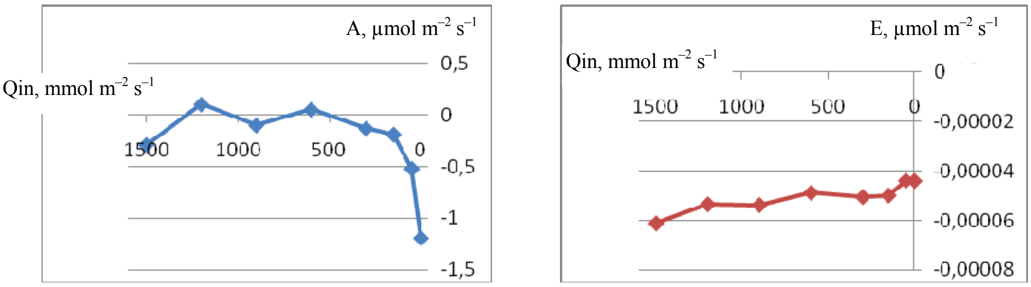
Next, measurements were taken to study the correlation between transpiration and photosynthesis rates and the CO_2 content in the air. The following data were obtained.

In all samples, as the CO_2 content in the air decreased, the rate of photosynthesis decreased. Then, as the CO_2 content increased, the rate of photosynthesis increased, and when CO_2 levels decreased again, the rate of photosynthesis also decreased. The maximum photosynthesis rates were observed in the samples grown in the phytotron at a CO_2 concentration of 1200 mmol/mol^{-1}, and in the samples grown under natural conditions at 1000 mmol/mol^{-1}. The minimum photosynthesis rates were observed at 0 mmol/mol^{-1} in all samples (Figure 6).

No clear dependence was found when studying the change in transpiration rate with respect to the CO_2 content (Figure 7).



a



b

Figure 2. The relationship between the rate of photosynthesis (A) and transpiration (E) and light intensity (Qin):
a – sample 4; *b* – sample 18

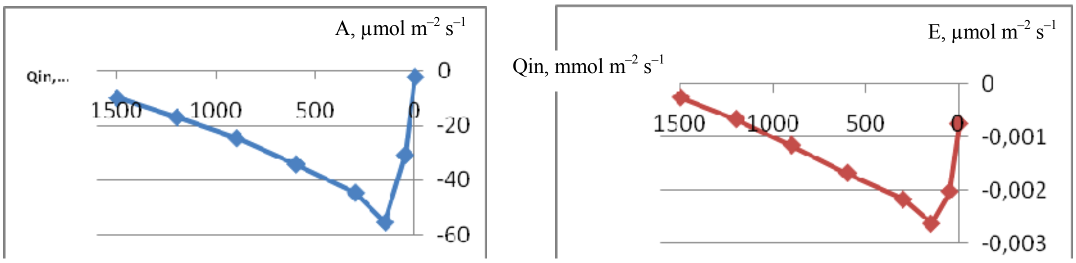
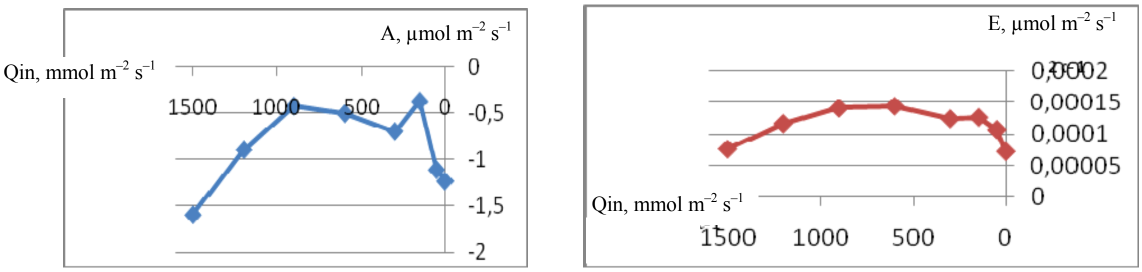


Figure 3. The relationship between the rate of photosynthesis (A) and transpiration (E) and light intensity (Qin): sample 13



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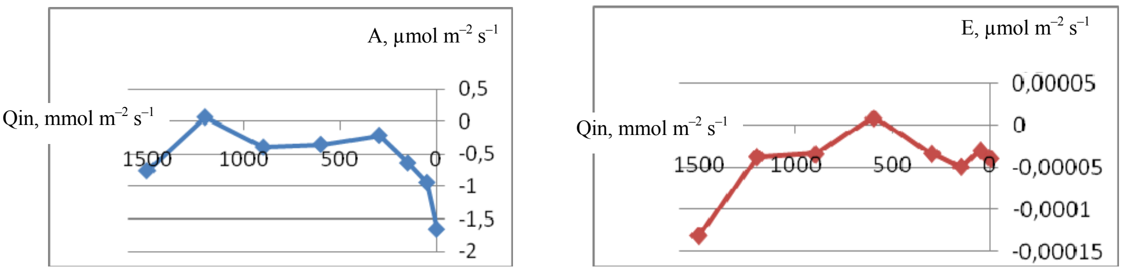


b

Figure 4. The relationship between the rate of photosynthesis (A) and transpiration (E) and light intensity (Qin): 0
a – sample 3; *b* – sample 20

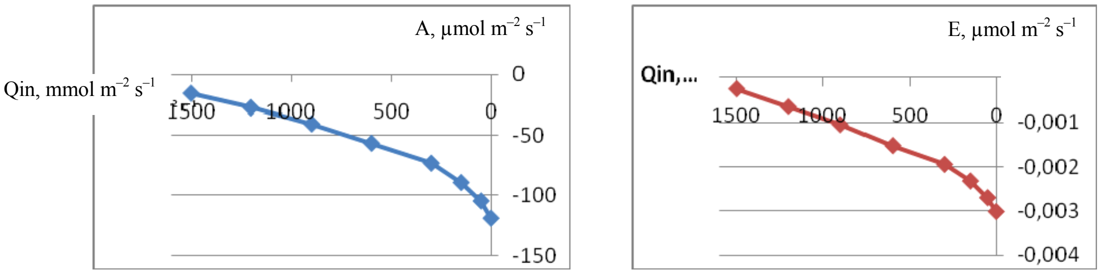
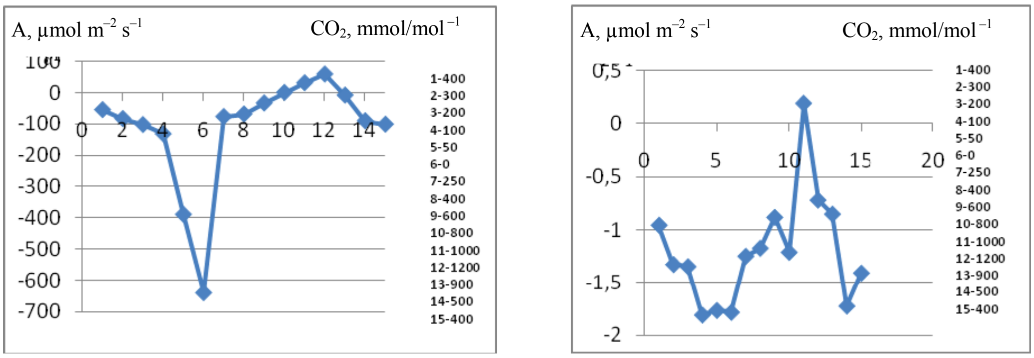
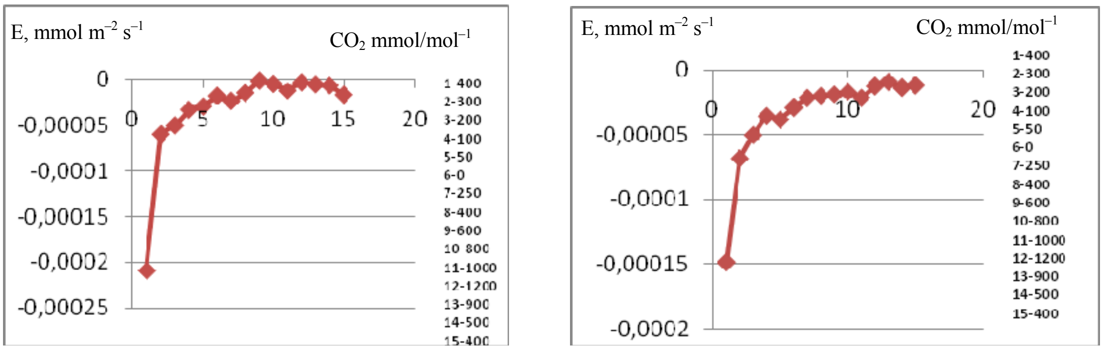


Figure 5. The relationship between the rate of photosynthesis (A) and transpiration (E) and light intensity (Qin): sample 4



a *b*

Figure 6. The relationship between the rate of photosynthesis (A) and transpiration (E) and CO_2 concentration:
a – sample growing in a phytotron; *b* – sample growing in natural conditions



a *b*

Figure 7. The relationship between the rate of photosynthesis (A) and transpiration (E) and CO_2 concentration:
a – sample growing in a phytotron; *b* – sample growing in natural conditions

Minimal initial values of transpiration rate are observed at a CO_2 concentration of 400 mmol mol^{-1}. Then, as the CO_2 concentration decreases to 300–200 mmol mol^{-1}, a sharp increase in transpiration rate is observed. With further changes in CO_2 concentration, the transpiration rate increases slightly and remains within certain limits.

CONCLUSION

Thus, a direct correlation was observed between the reduction in light intensity and the decrease in photosynthesis rate, and an inverse correlation between the decrease in light intensity and the transpiration rate for the samples growing in the phytotron. For the samples growing under natural conditions, a parabolic correlation was identified between light intensity and both photosynthesis and transpiration rates.

When studying the effect of CO_2 concentration in the air on the photosynthesis rate, a direct correlation was observed for all samples: a decrease in CO_2 concentration in the air resulted in a decrease in photosynthesis rate, while an increase in CO_2 concentration led to an increase in photosynthesis rate. No clear correlation was found for the change in transpiration rate with respect to CO_2 concentration.

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ИНТРОДУКЦИЯ ХВОЙНЫХ ВИДОВ В ДЕНДРАРИИ СИБГУ им. М. Ф. РЕШЕТНЕВА

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Приведены сведения о коллекции хвойных видов в дендрарии СибГУ. Начало создания дендрария относится к 1948 г. под руководством профессора В. Э. Шмидта. В настоящее время коллекция представлена видами дальневосточной (Pinus koraiensis Siebold et Zucc., Pinus pumila (Pall.) Regel., Larix sibirica Ledeb.), *европейской (Picea abies* (L.) Karst., *Juniperus communis* L.), *сибирской* (*Abies sibirica Ledeb*., *Larix sibirica* Ledeb., *Picea obovate* Ledeb, *Pinus sibirica Du Tour*), *североамериканской (Picea engelmannii Engelm, Thuja occidentalis L., Juniperus sabina* L.) *флор, Японии* (*Larix leptolepis* Gord.). *Наибольшей высоты достигли Pinus sibirica, Pinus koraiensis, Picea obovata, Abies sibirica (15–23 м). Большинство растений находятся в хорошем состоянии. Семеношение разной интенсивности отмечено у всех видов. Из семян, собранных в дендрарии, выращивается посадочный материал (сеянцы собственной репродукции), использованный для получения потомства второго поколения.*

Ключевые слова: *интродукция, дендрарий, коллекция, флора, хвойные виды, Сибирь.*

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INTRODUCTION OF CONIFEROUS SPECIES IN THE ARBORETUM OF RESHETNEV SIBERIAN STATE UNIVERSITY OF SCIENCE AND TECHNOLOGY

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Information about the collection of coniferous species in the arboretum of Siberian State University is given. The creation of the arboretum began in 1948 under the guidance of Professor V. E. Schmidt. At present, the collection is represented by species of the Far Eastern (Pinus koraiensis Siebold et Zucc., Pinus pumila (Pall.) Regel., Larix sibirica Ledeb.), European (Picea abies (L.) Karst., Juniperus communis L.), Siberian (Abies sibirica Ledeb., Larix sibirica Ledeb., Picea obovate Ledeb, Pinus sibirica Du Tour), North American flora (Picea engelmannii Engelm, Thuja occidentalis L., Juniperus sabina L.), Japan (Larix leptolepis Gord.). Pinus sibirica, Pinus koraiensis, Picea obovata, Abies sibirica reached the highest altitude (15–23 m). Most of the plants are in good condition. Seeding of varying intensity has been observed in all species. From the seeds collected in the arboretum, planting material (seedlings of their own reproduction) is grown to obtain second-generation offspring.

Keywords: *introduction, arboretum, collection, flora, coniferous species, Siberia.*

INTRODUCTION

Scientific researches on introduction of woody plants are carried out in different regions of Russia and abroad. Thus, large collections of introduced plants are presented in the Siberian Botanical Garden of Tomsk State University [2], Central Siberian Botanical Garden (Novosibirsk) [4], Botanical Garden of Voronezh State Technological Academy [7], Khakassia Arboretum [5], Introduction Centre of Kaliningrad Oblast [12], Main Botanical Garden of the Russian Academy of Sciences (Moscow) [10], Botanical Garden of St. Petersburg State Forestry Technical University named after S.M. Kirov [14], etc.

Recently, much attention has been paid to the breeding of introduced coniferous species, in particular, junipers and thuja, which are widely used in landscaping of the European part of Russia and can be used not only in the settlements of Siberia, but also indoors, as they are one of the most phytoncidal plants with high sanitary-hygienic and decorative properties. It is known that one plant of juniper indoors can completely destroy pathogenic microflora within a day [13].Pinus koraiensis is of great ecological value, its phytomass plays an important role in environmental health improvement [3].

OBJECTS AND METHODS OF RESEARCH

Arboretum of Reshetnev University began to be created under the guidance of Professor Walter Eduardovich Schmidt in 1948. In 2023 the arboretum celebrated its 75th anniversary.

Formation of the mother branch of introducers, collection of cedar pines of different geographical origin was initially carried out by E.P. Verkhovtsev, I.Yu. Koropachinsky, V.V. Ogievsky, O.P. Olisova. Since 1977 the area of the arboretum was increased under the direction of the head of the department R.N.Matveeva. There were planted introductions, selected trees of cedar pines (*Pinus sibirica, Pinus koraiensis, Pinus pumila*).

There is a collection of poplar trees of Prof I.Y. Koropachinsky. [1].

At present, more than 200 species of trees and shrubs grow in the arboretum. The researches for which are ongoing under the direction of O.F.Butorova, N.P.Bratilova, A.B. Romanova, K.V. Shestak, E.A. Usova and others [9].

The arboretum is located in the green zone of Krasnoyarsk on the left bank (second terrace) of the Yenisei at an altitude of 250 m above sea level, in the 40–41st quarters of the Karaulniye forest area in the Training and Experimental Forestry of Reshetnev University (green zone of Krasnoyarsk), the territory of which is a part of the Central Siberian subtaiga-forest-steppe region [11]. The arboretum is located on the slope of southern exposition with steepness of 2–3° and currently occupies the area of 9.1 hectares. Geographical coordinates are 56°N, 92°40'E.

The soil is grey forest light loamy slightly podzolised. The arable horizon is characterised by significant humus content (4,2–6,4 %).The sum of absorbed bases is 19,4-21,8 mg-eq. per 100g of soil. The reaction of soil solution is slightly acidic (pH-salt = 6,0–6,8). The content of mobile forms of phosphorus is high (32,0–38,4 mg according to Kirsanov), of potassium is average (10,0–15,5 mg per 100 g of soil according to Maslova).

In the south of Central Siberia, the climate is sharply continental, characterised by a complex set of exogenous factors to which plants are exposed during overwintering. Early autumn and late spring frosts often cause damage to shoots and generative organs. Sometimes the root system of plants is squeezed out by freezing and thawing of the soil. In the study area, the maximum air temperature reaches 36º, the minimum is minus 44º. The average annual air temperature is 0.6º. The sum of effective temperatures is 1400–2000º. The annual precipitation averages 496 mm.

RESULTS AND THEIR DISCUSSION

There is a collection of coniferous species of introduced plants from Europe, North America, Japan, Far East in the arboretum of Reshetnev University. Many introduced plants have successfully suited to the climate in harsh conditions and give seed progeny. Some conifers growing in the arboretum are presented in the figure.

The collection funds of the Arboretum are annually increased by collecting seeds from selected mother plants, as well as from other arboretums and Botanical Gardens.

The Arboretum includes several sections. The mother section ‘A’ was created in the period from 1949 to 1963 and occupies an area of 1.6 hectares. Here the introduced plants, which were planted in rows at a distance of 2.5–4 m from each other grow. Section ‘B’ with an area of 0.8 ha was formed in 1961–1978 on the place of the sowing section from the remaining seedlings and additional row plantings in the fourth and ninth sections. Section ‘C’, called ‘arboretum’, occupies an area of 0.8 ha. It was created in 1953–1959 according to the geographical principle. Section ‘E’ (European-Siberian flora) with the area of 1.12 ha has been created in landscape style since 1960, ‘D’ (Far Eastern flora) with the area of 0.84 ha has been created since 1970.

In section ‘A’ of coniferous species there are *Pinus sibirica* trees of different geographical origin, the seeds of which were obtained from plantations growing from Leninogorsk to Yakutsk, having a height of 10.2–14.5 m [6; 8].

There are *Pinus sibirica, Pinus koraiensis, Pinus pumila, Larix gmelinii* trees in the mother section ‘B’. The height of plants varies from 1.8m (*Pinus pumila*) to 10.5–13.0m (*Pinus sibirica, Pinus koraiensis*) [8], as well as grafted plants of *Pinus sibirica* on *Pinus sylvestris L.* rootstock, made by the method of ‘ablation’ by E.P. Verkhovtsev in 1953. *Picea abies* is characterised by high ornamental value.

Section ‘C’ consists of species of Siberian, East Asian and North American floras. *Picea obovata, Pinus sibirica and Pinus koraiensis* are represented by the largest number of specimens. *Picea obovata, Abies sibirica Ledeb* have the maximum height. *Picea engelmannii* has lost its ornamental value due to heavy overcrowding.

Section “E” (European and Siberian floras) consists of *Juniperus communis, Juniperus sabina, Picea abies, Larix sibirica.* The greatest height (11–15 m) is reached by trees *Picea obovata, Pinus sibirica, Larix sibirica*. *Juniperus communisL.,Juniperus sabina* are characterised by high ornamental qualities.

Exposition of the Far East (Section ‘D’) includes *Larix leptolepis, Pinus caryensis* from the East Asian floristic zone.

From seeds collected in the arboretum, planting material (seedlings of own reproduction) is grown and used for obtaining second generation offspring. An important task is selection and reproduction of the most adapted individuals on the basis of assessment of individual variability of morphological traits in the formed collections.

Seed production of different intensity was observed in all species. *Picea abies, Pinus sibirica* are characterised by high yield. Average yield is observed in *Pinus koraiensis.* Cedar pines, which produce edible seeds, are of great interest. Most plants of these species are in good condition [3, p. 17].

The most ornamental plants are *Picea abies, Juniperus communis, Juniperus sabina*.

Some representatives of coniferous plants in the Arboretum of Reshetnev University

CONCLUSIONS

The conducted studies have shown that *Picea abies, Pinus sibirica, Pinus koraiensis, Juniperus communis L., Juniperus sabina,* tested for a long time in the arboretum of Reshetnev University can be widely used in the conditions of the green zone of Krasnoyarsk.

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ТАКСАЦИОННЫЕ ПОКАЗАТЕЛИ КЛОНОВ ПЛЮСОВЫХ ДЕРЕВЬЕВ ЕЛИ ЕВРОПЕЙСКОЙ В АРХИВЕ КЛОНОВ В НИЖЕГОРОДСКОЙ ОБЛАСТИ

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Исследовали таксационные показатели клонов плюсовых деревьев ели европейской (Picea abies (L.) Karsten) в архиве клонов № 3 на территории Семеновского районного лесничества Нижегородской области. Он создан в 1984 году привитыми саженцами в возрасте 2 лет. Источником привоя были плюсовые деревья, произрастающие в естественных насаждениях того же региона в типах лесорастительных условий B_2 и B_3. Их возраст на момент отбора достигал от 60 лет до 140 лет, а таксационные показатели составили: высота – от 24 м до 70 м; диаметр – от 24 см до 35 см. Размещение посадочных мест было 3×3 м, схема смешения клонов – рядовая при исходной повторяемости каждого ортета 3…12 раметами. Первоначальная площадь составила 0,4 га, тип лесорастительных условий на ней соответствовал категории B_2. Рельеф участка равнинный с серыми лесными почвами. Он имеет географические координаты N56°44'18,97" E44°20'49,29", отнесен к району хвойно-широколиственных (смешанных) лесов европейской части Российской Федерации и входит в зону хвойно-широколиственных лесов. Лесорастительные условия региона вполне благоприятны для произрастания и семеношения ели европейской. Сбор первичной лесоводственной информации осуществлен полевым стационарным методом при сплошном перечете деревьев на всей площади архива клонов с соблюдением принципа единственного логического различия, типичности, пригодности, надежности и целесообразности опыта. Отмечена неоднородность вегетативного потомства плюсовых деревьев ели европейской по таксационным показателям, которая проявилась как на уровне различий между группами одноименных клонов, так и в пределах каждой из них.

Плюсовые деревья ели европейской, представленные своими вегетативными потомствами в составе обследованного архива клонов, в значительной мере различались между собой по основным таксационным показателям. По высоте ствола наибольшее среднее (19,83±1,14 м), у рамет ортета К-102, превосходило наименьший аналогичный показатель (10,50±1,85 м) у клонов с индексом К-100, в 1,88 раза или на 9,33 м. Обобщенное для всего массива данных среднее достигло 14,71±0,34 м при соотношении между абсолютными пределами (max = 3 м; min = 3,50 м) как 6,57 и абсолютном диапазоне, равном 19,50 м. Изменчивость признака, при этом, соответствовала повышенному уровню по шкале Мамаева (Cv = 28,41 %).

Ключевые слова: *ель европейская, плюсовые деревья, клоны, архив клонов, таксационные показатели, изменчивость, наследственная обусловленность.*

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TAXATION INDICATORS OF THE NORWAY SPRUCE PLUS TREES IN THE CLONE ARCHIVE IN THE NIZHNY NOVGOROD REGION

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The taxation indicators of clones of the Norway spruce (Picea abies (L.) Karsten) plus trees were studied in the clone archive No. 3 on the territory of the Semenovsky district forestry of the Nizhny Novgorod region. It was created in 1984 by grafted seedlings at the age of 2 years. The source of the graft was plus trees growing in natural plantings of the same region in the types of forest growing conditions B_2 and B_3. Their age at the time of selection ranged from 60 years to 140 years, and the taxation indicators were: height – from 24 m to 70 m; diameter – from 24 cm to 35 cm. The seating arrangement was 3×3 m, the clone mixing scheme was ordinary with the initial repeatability of each orthet *by 3...12 ramets. The initial area was 0.4 hectares, the type of forest conditions on it corresponded to category B_2. The terrain of the site is flat with gray forest soils. It has geographical coordinates N56°44'18.97" E44°20'49.29", is assigned to the area of coniferous-deciduous (mixed) forests of the European part of the Russian Federation and is included in the zone of coniferous-deciduous forests. The forest growing conditions of the region are quite favorable for the growth and seed-bearing of Norway spruce. The collection of primary forestry information was carried out by a stationary field method with a continuous enumeration of trees over the entire area of the clone archive in compliance with the principle of the only logical difference, typicality, suitability, reliability and expediency of the experiment. The heterogeneity of the vegetative offspring of the plus trees of the Norway spruce was noted in terms of taxation indicators, which manifested itself both at the level of differences between groups of the same name clones, and within each of them. The plus trees of the Norway spruce, represented by their vegetative offspring as part of the examined clone archive, differed significantly among themselves in terms of the main taxation indicators. In terms of trunk height, the highest average (19.83±1.14 m), in the frame of the K-102 orthet, exceeded the lowest similar indicator (10.50±1.85 m) in clones with the K-100 index, by 1.88 times or by 9.33 m. The average generalized for the entire data set reached 14.71±0.34 m with the ratio between absolute limits (max = 23 m; min = 3.50 m) both 6.57 and an absolute range equal to 19.50 m. The variability of the trait, at the same time, corresponded to an increased level on the Mamaev scale (Cv = 28.41 %).*

Keywords: *Norway spruce, plus trees, clones, clone archive, taxation indicators, variability, hereditary conditionality.*

INTRODUCTION

One of the vectors set by the Strategy for the Forest Complex Development of the Russian Federation for the period up to 2030 is the continuous increase in the resource, ecological and recreational potential of domestic forests, as well as through their selective improvement. First of all, this applies to the most important forest-forming species, among which the Norway spruce (*Picea abies* (L.) Karsten) occupies one of the central places not only in the Russian Federation [15; 16; 17; 18; 21], but also in the countries of central Europe [56], Bulgaria [25], Romania [26; 55], Sweden [30; 34; 48], Finland [35; 62], Lithuania [57] and many other European countries [32], from where it is actively introduced for use in plantation forestry in Canada [31] and Japan [42]. Possessing a unique set of useful features and properties, it serves as an object of diverse research by native [5; 7; 9; 10; 18; 21] and foreign [41; 44; 52; 63] scientists for a long period of time. The most important areas of research are seed production [61], forest crops [17; 47] and plantations [38; 51], photosynthesis, pigment composition and other pine needles characteristics [4; 5; 15; 21; 42; 43; 46; 54; 60], biotechnologies [45] and physiology [6; 14; 27; 28; 40]. A lot of work has been devoted to identification the breeding potential of this species, assessment the scale of variability and prospects for creating forest seed plantations, and formation reserves of genetic material [12; 29; 36; 37; 59]. As a representative of the native flora of the Volga Federal District, the spruce occupies vast areas in the Nizhny Novgorod region [1; 2; 4; 8; 10; 18; 19; 22]. Here it is introduced into the composition of forest crops, protective plantings for various purposes and structures, and planting of greenery capable of effectively performing sanitary, aesthetic, decorative, and recreational-balneological functions. However, there are still few detailed and comprehensive studies of the available collections of plus trees.

The purpose of the study is to evaluate the hereditary conditionality of the taxation indicators variability of Norway spruce trees represented by vegetative offspring as part of the clone archive on the territory of the Semenovsky district forestry of the Nizhny Novgorod region.

MATERIALS AND METHODS

The object of the study was the clones of 21 Norway spruce trees, centered in the archive of clones No. 3. It was created in 1984 by grafted seedlings, which were 2 years old at the time of planting. The source of the graft for their production was the plus trees growing in the same region in natural plantations formed in the B_2 and B_3 types of forest conditions, and the cleft grafting was performed by specialists of the state autonomous institution of the Nizhny Novgorod region “Semenovsky specialized forestry association” (“Semenovsky spetssemleskhoz”). The taxation indicators of the plus trees varied at the time of selection: in height – from 24 m to 35 m; in diameter – from 24 cm to 70 cm, the age of selection from natural plantings ranged from 60 years to 140 years. The specified object of the unified genetic breeding complex is located in forest allotment No. 9 of the forest quarter No. 139 within the boundaries of the Semenovsky district forestry of the Semenovsky regional Forestry of the Ministry of Forestry and Wildlife Protection of the Nizhny Novgorod region. The area has geographical coordinates N56.74161° E44.35436°. Its territory, according to the current forest zoning, is included in the coniferous-broadleaf (mixed) forests area of the European part of the Russian Federation (coniferous-broadleaf forests zone), and according to the forest seed zoning it is included in the third spruce forest seed area. Climatic and soil conditions are quite favorable for this species for growth and seed production [1; 2; 19; 22], this is evidenced by the work on the creation of forest crops [19; 20; 21] and numerous permanent forest seed facilities and a single genetic breeding complex [4; 5; 8; 10; 15; 16]. The design placement of planting spots on the site was 3×3 m, the density of the initial planting was 1111 pcs/ha, the clone mixing scheme was ordinary, with the initial repeatability of each ortet of 3...12 ramets. The possible volume of harvesting cuttings of each clone per year (on average) is 100 pcs. The initial area was 0.4 hectares, and the type of forest conditions on it corresponded to category B_2.

At the moment, the herbaceous cover of the clone archive contains mainly cereal vegetation with an admixture of strawberries, St. John's wort, oregano and some other herbaceous species. The primary forestry information was collected by the stationary field method, observing the principle of a single logical difference, as well as the requirements for typicality, suitability, reliability and expediency of the experience. In the course of full-scale taxation, a complete enumeration of 150 trees was carried out. The height was measured with a Suunto PM-5/360 PC altimeter with a scale accuracy of 0.1 m, the diameter at a height of 1.3 m with a measuring stick with an accuracy of 1 cm, the diameter of the crown projection in two directions and the distance to the first knot with a measuring pole with an accuracy of 1 cm. The accumulated experience of taxation of such objects was taken into account in the work [13; 23; 24]. Along with morphometric indicators recorded during direct accounting, the work used derived features, the use of which in forestry and biological research of a wide range of species is traditional and very productive [3; 53]. They are successfully used in various breeding programs [4; 5; 8], including the study of various species of spruce [10; 15; 16; 18]. Statistical data processing was performed according to the current recommendations [11; 33; 39; 49; 50; 58; 64].

THE RESULTS AND THEIR DISCUSSION

The plus Norway spruce trees, represented by their vegetative offspring in the examined clone archive No. 3, differed significantly in terms of basic taxation indicators (Fig. 1-5).

A comparison of estimates of one of the main criteria by which plus trees are traditionally selected from natural plantings – trunk height – showed that the highest average (19.83±1.14 m) observed in the ramets of K-102 ortet was higher than the lowest similar indicator (10.50±1.85 m) recorded in clones with the K-100 index, by 1.88 times or by 9.33 m. The average generalized for the entire data set (see Fig. 1) reached 14.71±0.34 m with the ratio between the absolute limits (max = 23 m; min = 3.50 m) as 6.57 and an absolute range of 19.50 m. At the same time, the variability of the trait corresponded to an increased level on the Mamaev scale (Cv = 28.41%).

Another basic indicator, which is also used for mass selection of plus trees by phenotype, is the diameter of their trunk at a height of 1.3 m (see Fig. 2).

This parameter turned out to be less stable (see Fig. 2). The largest average value (24.20±1.60 cm) observed in the K-58 ramets exceeded the corresponding smallest value (12.50±2.22 cm) observed in the K-57 plus tree clones by 1.93 times or by 11.7 cm. At the same time, the average generalized for the entire experimental section (Total variant) was 17.92±0.57 cm; the ratio between the absolute limits (max = 38.00 cm; min = 5.00 cm) was estimated as 7.60 with an absolute range of 33.00 cm. The variability in the generalized data set reached a high level on the Mamaev scale (Cv = 39.35%).

An indicator that is largely significant for describing the general biological state of woody plants – the diameter of the trunk at the root neck – demonstrated approximately the same level of heterogeneity (see Fig. 3).

Compared to the fundamental similarity with the ratio of the plus trees average values according to the previous indicator, the highest estimate of this parameter (31.83.78±3.35 cm), noted in the ramets of the K-99 ortet, exceeded the corresponding lower indicator (15.00±2.38 cm), observed in the clones of the K-57 plus tree, by 2.12 times or by 16.83 cm. The unified average for the entire data array (Total variant) was 22.10±0.67 cm with the ratio between the absolute limits (max = 44.0 mm; min = 6.0 cm) as 7.33 and the absolute range equals to 38.0 cm. The general background of the variability of this indicator was slightly higher and, as in the previous case, corresponded to a high level on the Mamaev scale (Cv = 37.62 %).

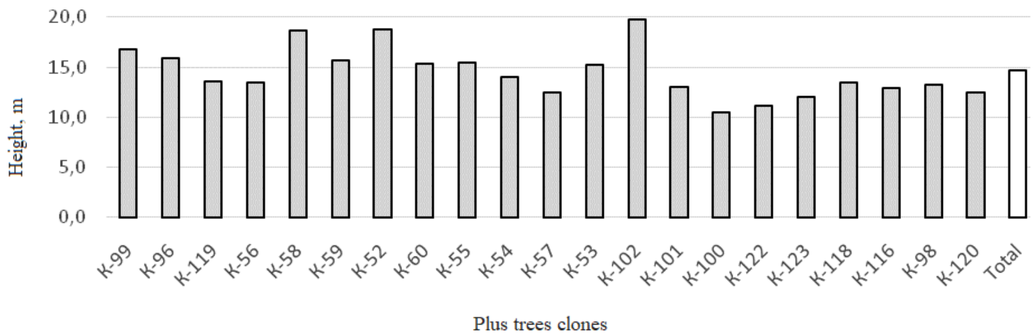

Fig. 1. The height of the trunk of the plus trees' clones of the Norway spruce

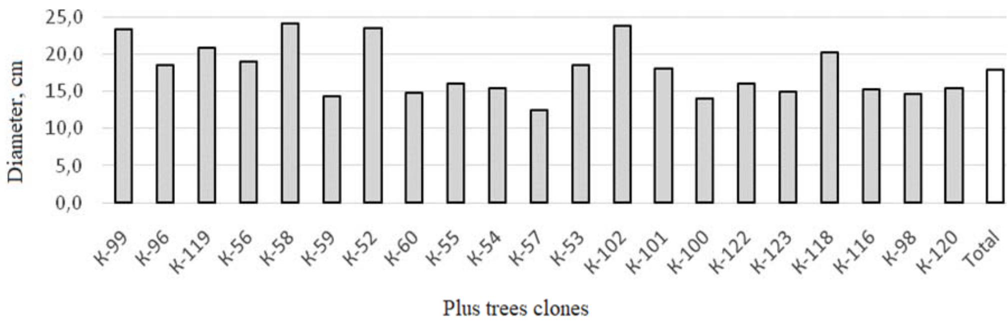

Fig. 2. Trunk diameter of Norway spruce clones at a height of 1.3 m

A visual representation of the trees growth in height and the preservation of its rhythm during ontogenesis is provided by information on the magnitude of the axial distances between the whorls that appeared on the trunk (see Fig. 4). The highest average value (69.67±24.73 cm) for this trait was observed in K-99 clones. The lowest value of the indicator (24.40±10.60 cm) was recorded in K-56 clones in the same archive. Such estimates created a difference between them of 45.27 cm or 2.85 times. Compared to this, the average generalized for all experimental plots (Total variant) acquired a value of 37.57±1.39 cm, and the ratio between the absolute limits (max = 191 cm; min = 10.50 cm) was 18.19 with an absolute range of 180.50 cm.

The variability of the studied characteristic was even higher here and corresponded to a very high level on the Mamaev scale (Cv = 46.01%).

The basic taxation indicator determining the volume of the trunk of a tree – the cross–sectional area at a height of 1.3 m - was even more variable (see Fig. 5).

As it was found, the largest average value of this trait (477.99±65.24 cm^2) was observed in the ramets of the K-58 plus tree, and the smallest area (134.30±45.64 cm^2) was observed in clones with the K-57 index. The estimates obtained during the statistical processing of the material formed a difference of 343.69 cm^2 between them, which created an excess of 3.56 times. The average generalized for all accounting trees (Total variant) was 290.87±17.40 cm^2. Compared to this, the ratio between the absolute limits (max = 1134.11 cm^2; min = 19.63 cm^2) was represented as 56.7 with their range of 1114.48 cm^2. In the estimates for the coefficient of variation (Cv = 74.22 %), the variability of this taxation indicator was even higher and corresponded to a very high level on the Mamaev scale.

An important technological characteristic of woody plants, which is of great economic importance, is the length of the branchless zone of the trunk, which depends on its natural pruning ability and is determined by the distance from the soil surface to the first knot (see Fig. 6), in our case, to the first living one. The variability of this taxation indicator can also be recognized as one of the highest (Cv = 72.07%), and in estimates of the coefficient of variation it corresponds to a very high level of the Mamaev scale. At the same time, a significantly larger average (5.40±0.70 m) was recorded for the clones of the K-96 plus tree, and the smallest area (0.75±0.22 m) was recorded for the ramets of the K-99 ortet.

The difference in estimates was 4.65 m, or 7.2 times. The generalized average for all was 2.45±0.14 m. Compared to this, the absolute range of limits (max = 10.00 m; min = 0.08 m) was 9.92 m with their ratio being 125.0 exactly.

The most informative indicator of the stacked-volume ratio of the trunk in the taxation is its taper, which was relatively aligned according to the experimental variants with some unavoidable differences in the surveyed area (see Fig. 7).

As it was found, towards this indicated trait, the largest taper (0.159±0.02 cm/m) was typical for the vegetative offspring of the K-119 plus tree, and the smallest (0.089±0.01 cm/m) was inherent in the clones of the K-59 plus tree. The difference in estimates was 0.07 cm/m, or 1.78 times. The average generalized for all experimental variants was 0.12±0.001 cm/m with an absolute limit range (max = 0.24 cm/m; min = 0.06 cm/m) of 4.04 cm/m and their ratio equal to 14. According to the coefficient of variation within the entire data set (Cv = 23.91%), the variability corresponded to the average level of the scale we accepted.

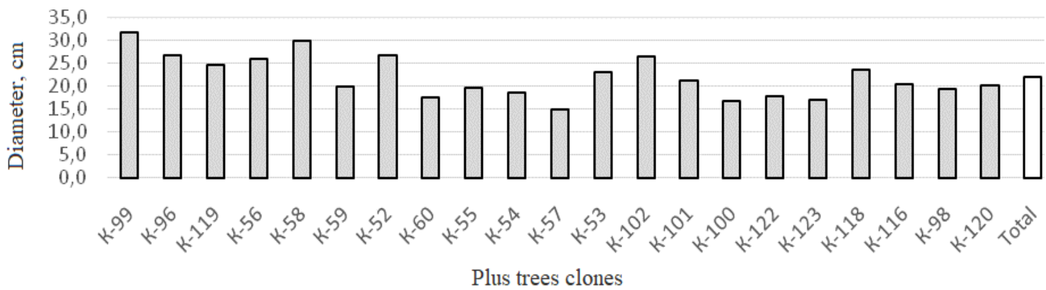

Fig. 3. The diameter of the trunk of the plus trees clones of the Norway spruce at the root neck

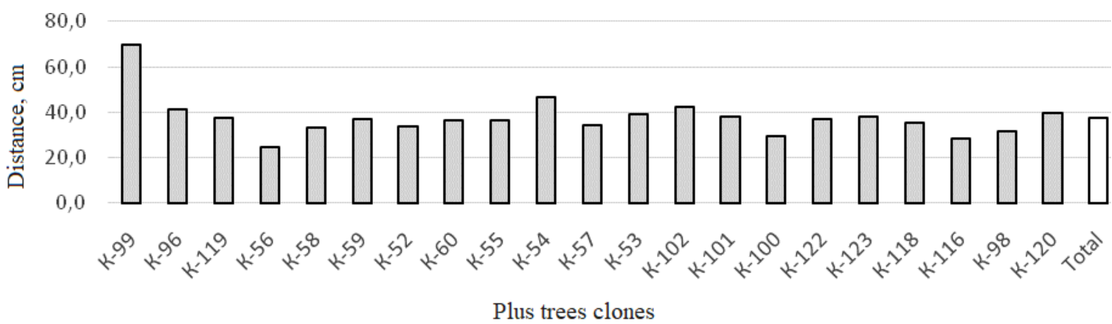

Fig. 4. The average distance between the whorls on the trunk of the plus trees clones

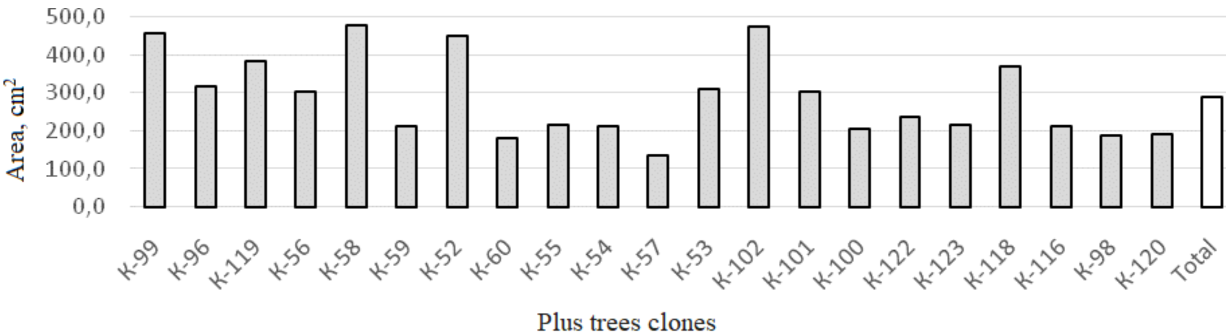

Fig. 5. The cross-sectional area of the trunk at a height of 1.3m

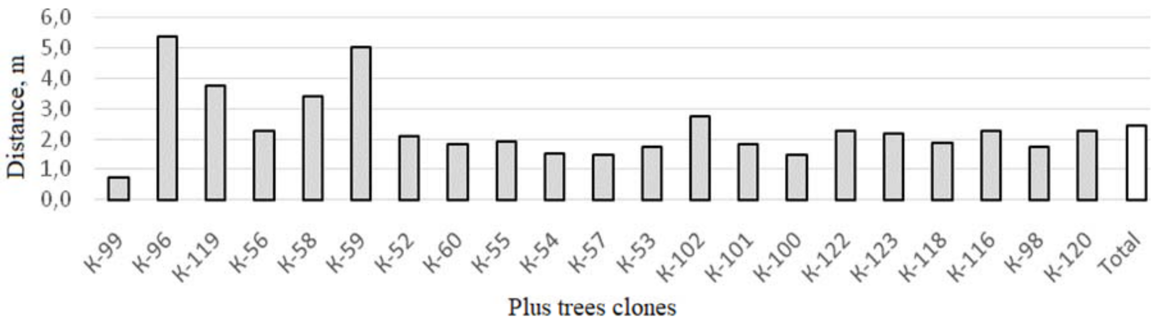

Fig. 6. The distance from the soil surface to the first knot

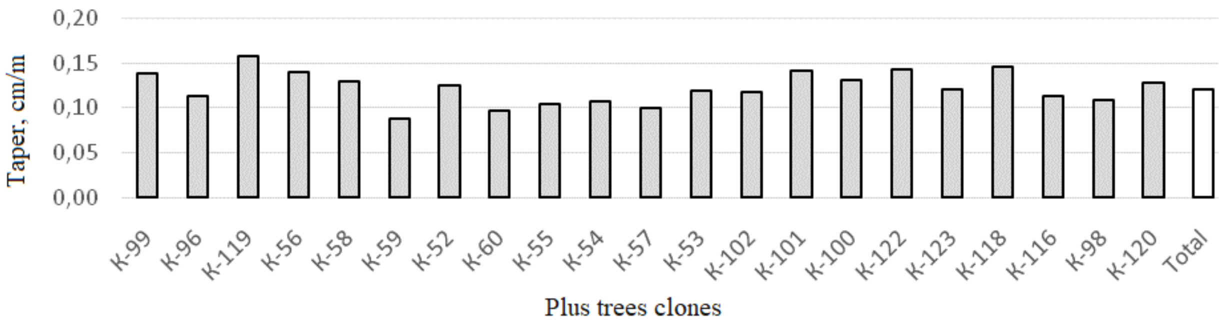

Fig. 7. The taper of the trunk of the spruce trees in the clone archive

Since all the phenotypic differences observed in the experiment appeared on an aligned ecological background within the borders of a single site with the same schemes of agrotechnical and forestry care, there are grounds for recognizing the genotypic features of the plus trees introduced into the studied clone archive as the causes of their occurrence. A one-factor analysis of variance confirmed the existence of significant differences between them (Table 1).

In the vast majority of cases (13 out of 15), with the exception of the distance to the first knot (trait 4) and the coefficient of crown asymmetry (trait 15), the differences between the plus trees were substantial at the 5% significance level: Fischer's calculated criteria exceeded the thresholds for the experimentally determined number of degrees of freedom. For traits with confirmed significance of the differences, they took values from 1.70 (trait 6) to 6.74 (trait 14) with a critical threshold of 1.64 (see Table 1). This outcome of the stage of variance analysis made it possible to continue its implementation in terms of obtaining estimates of the share of the endogenous differences influence between plus trees on the formation of the general background of phenotypic variance.

In calculations based on the Plokhinsky's algorithm, this effect was more represented (50.35±7.47%) in terms of the average crown diameter (trait 14), while its smallest value (20.38±11.97%) was recorded in terms of the average distance between the whorls (trait 6).

Sufficiently high scores were obtained for three more traits – the distance to the first living knot (trait 5); crown diameter in the N-S direction (trait 12); crown diameter in the E-W direction (trait 13): 44,46±8,35%; 42,66±8,62%; 43,86±8,44% accordingly.The estimates of the remaining traits, provided that they were reliable, were placed in the specified range. The usage of the Snedecor algorithm in calculations of similar indicators gave a completely comparable, though somewhat noticeably smaller, result. In the analysis variants with confirmed significant differences between the compared plus trees, the estimates of the proportion of the interclonal differences influence are statistically reliable, which is confirmed by the calculated values of the reliability indicators of the estimates of the factor's influence strength (F_h^2), which exceeded the corresponding tabular values not only by 5 percent, but also by 1 percent significance level.

Estimates of the differences significance (see the table) between the compared vegetative offspring of plus trees according to the analyzed characteristics made it possible to set a limit beyond which the actual difference in average values acquires the status of significant. For example, in terms of trunk height (trait 1), the K-102 plus tree by the LSD (least significant difference) estimates at a 5% significance level showed significant upward deviations from the 17 others included in the considered archive of clones No. 3.

The ramets of the K-58 and K-52 plus trees had 12 such differences with other elements of the same assortment, the ramets of the K-100 and K-122 plus trees had 9 each, and the ramets of the K-99 plus tree had 7. A number of other plus trees (K-119, K-56, K-59, K-60, K-55, K-54, K-53, K-118, K-98), on the contrary, had a significant difference with only 3 others in the range under consideration. In the assessment according to the stricter criterion in the Tukey's test (D_{05}), these trends remained. A similar pattern was observed for other taxation indicators of the studied plants, despite the fact that each of them had its own specificities in this regard. The majority of the analyzed traits are characterized by the prevailing (up to 96.87%) influence of external factors on the general background formation of the phenotypic variance of the taxation indicators of the plus trees' vegetative offspring introduced into the archive of clones No. 3. It can be stated that the assortment of the clone archive No. 3, created in accordance with current regulations and standards, is represented by the vegetative offspring of Norway spruce trees, which significantly differs at the interclonal level in most of the taxation indicators. Growing together within the borders of the same plot on an ecological background aligned according to basic parameters, representatives of clones of different name showed phenotypic heterogeneity, the cause of which is largely related to the specifics of their genotypes. This corresponds to the ideas about the scale of hereditary conditionality of the taxation indicators' phenotypic variance of many coniferous species and was confirmed by the results of the variance analysis.

The significance of the differences between the plus trees clones in terms of taxation indicators[1, 2]

Accounting zones, traits	F_{ex}	The share of the factor's influence ($h^2 \pm s_h^2$)						Criteria for differences	
		Plokhinsky			Snedecor				
		h^2	$\pm s_h^2$	F_h^2	h2	$\pm s_h^2$	F_h^2	LSD_{05}	D_{05}
Trait 1	3,80	0,3638	0,0957	3,803	0,2774	0,1087	2,553	3,668	3,705
Trait 2	2,42	0,2672	0,1102	2,424	0,1632	0,1258	1,297	6,639	6,707
Trait 3	2,71	0,2892	0,1069	2,706	0,1894	0,1219	1,553	7,714	7,792
Trait 4	1,61	0,1945	0,1211	1,605	0,0766	0,1389	0,551	16,619	16,787
Trait 5	5,32	0,4446	0,0835	5,323	0,3719	0,0945	3,937	1,448	1,463
Trait 6	1,70	0,2038	0,1197	1,702	0,0877	0,1372	0,639	16,969	17,142
Trait 7	2,27	0,2544	0,1121	2,268	0,1480	0,1281	1,155	205,097	207,179
Trait 8	3,74	0,3597	0,0963	3,736	0,2725	0,1094	2,491	0,025	0,026
Trait 9	4,21	0,3879	0,0920	4,214	0,3056	0,1044	2,927	1,887	1,906
Trait 10	2,78	0,2947	0,1061	2,778	0,1958	0,1209	1,619	0,048	0,048
Trait 11	2,65	0,2849	0,1075	2,650	0,1843	0,1227	1,502	0,411	0,415
Trait 12	4,95	0,4266	0,0862	4,948	0,3509	0,0976	3,595	1,012	1,023
Trait 13	5,20	0,4386	0,0844	5,196	0,3649	0,0955	3,821	0,967	0,976
Trait 14	6,74	0,5035	0,0747	6,743	0,4402	0,0842	5,230	0,841	0,850
Trait 15	0,60	0,0827	0,1379	0,599	–0,0580	0,1591	–0,365	0,240	0,242

[1]Indicators: F_{ex} – Fischer's experimental criterion; F_{05}/F_{01} – tabular values of the Fischer criterion at the 5% and 1% significance levels accordingly – $F_{05/01}$ = 1,64 and 2,00; h^2 – an indicator of the factor's influence strength; $\pm s_h^2$ – an error of the indicator of the factor's influence strength; F_h^2 – an indicator of the reliability of the factor's influence strength; LSD_{05} – the least significant difference at the 5% significance level; D_{05} – the Tukey's criterion at the 5% significance level.

[2]Traits: 1) height; 2) diameter of the trunk at the height of 1.3 m; 3) the diameter of the trunk at the root neck; 4) the distance to the first knot; 5) the distance to the first living knot; 6) the average distance between the whorls; 7) the cross-section area of the trunk at a height of 1.3 m; 8) the trunk taper; 9) the ratio of the height of the trunk to its diameter at the height of 1.3 m; 10) the index of tree growth intensity; 11) the volume of the view cylinder; 12) crown diameter in the N-S direction; 13) crown diameter in the E-W direction; 14) average crown diameter; 15) crown asymmetry coefficient.

CONCLUSION

The plus Norway spruce trees in the clone archive on the territory of the Semenovsky district forestry of the Nizhny Novgorod region, represented by vegetative offspring that entered the reproductive phase of ontogenesis, differed visibly in basic taxation indicators: trunk height, diameter at a height of 1.3 m and at the root neck, taper, and also in relation to the height of the trunk to the area of its cross-section, which acts as an indicator of the intensity of tree growth. The recorded phenotypic differences between the examined clones of plus trees appeared on the aligned ecological background, within the borders of the same plot under the same forest growing conditions and general patterns of agrotechnical and forestry care, which may serve as a basis for recognizing the hereditary nature of the established variability. The analysis of variance confirmed the hereditary conditionality of the phenotypic manifestations of the taxation indicators of the Norway spruce trees' vegetative offspring.

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ОСОБЕННОСТИ ФОРМИРОВАНИЯ ПРИРОДОПОЛЬЗОВАНИЯ БОРЕАЛЬНОЙ ЗОНЫ ПРИЕНИСЕЙСКОЙ СИБИРИ

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Изучение вопросов природопользования было и остается одной из основных задач современной географии. В Приенисейской Сибири, протянувшейся с севера на юг на 30°, формируются разнообразные ландшафты от тундры, лесотундры до лесостепей, степей и горных лесов. В статье дается характеристика факторов формирования и функционирования природопользования на территории Сибири. Рассматриваются вопросы взаимодействия природы и общества, влияние на него деятельности человека, которая связана с эксплуатацией природно-ресурсного потенциала территории региона, его охраняют и воспроизводства природных ресурсов. Природопользование рассматривается в широком и узком смысле, говорится о факторах экономического развития во время перехода к рыночной экономике, анализируются вопросы демографии, структура населения, исторические и экологические факторы, а также промышленные и сельскохозяйственные производства. Авторами рассматривается региональное природопользование, то есть конкретный процесс взаимодействия, экономики и населения данного региона с природными факторами своей среды обитания. Региональное природопользование как система формируется и функционируют под воздействием внутренних и внешних факторов. К внешним относятся геополитическое положение изучаемого региона – наличие внешних границ, связи – исторические экономические, и другие с сопредельными государствами, и территорий, не имеющих общих с регионом границ, а также место региона во внутригосударственном разделении труда. К внутренним факторам формирования и функционирование региональной системы относятся природные социально-экономические исторические национальные этнические которые дифференцируют отдельные территории региона.Приведенный анализ природопользования позволил выявить особенности того, что основу развития современной экономики составляют процессы взаимодействия природы и общества, которые, осуществляются в процессе регионального природопользования характеризующиеся следующими чертами: природно-историческое единство и/или целостность; индивидуальность; привнесенность воздействия.

Ключевые слова: *природопользование, объект, черты и факторы формирования, региональная система, экология, природные ресурсы, функционирование региональной системы, урбанизация.*

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FEATURES OF NATURAL MANAGEMENT IN THE BOREAL ZONE OF THE YENISEI SIBERIA

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The study of nature management issues has been and remains one of the main tasks of modern geography. In the Yenisei Siberia, stretching from north to south for 30°, various landscapes are formed from tundra, forest-tundra to forest-steppes, steppes and mountain forests. The article characterizes the factors of formation and functioning of nature management in Siberia. The issues of interaction between nature and society, the impact on it of human activity, which is associated with the exploitation of the natural resource potential of the territory of the region, its protection *and the reproduction of natural resources are considered. Nature management is studied in a broad and narrow sense, it points the factors of economic development during the transition to the market economy, analyzes demographic issues, population structure, historical and environmental factors, as well as industrial and agricultural production. The authors consider regional nature management, that is, a specific process of interaction between the economy and the population of a given region with the natural factors of the habitat. Regional nature management as a system is formed and functions under the influence of internal and external factors. The external ones include the geopolitical position of the region under study, the presence of external borders, historical and economic ties with certain states, and territories that do not have common borders with the region, as well as the place of the region in the intrastate division of labor. The internal factors of the formation and functioning of the regional system include natural, socio-economic, historical, national and ethnic factors that differentiate individual territories of the region. The above analysis of nature management made it possible to identify the features of the fact that the basis for the development of the modern economy is the processes of interaction between nature and society, which are carried out in the process of regional nature management and are characterized by the following features: natural-historical unity and/or integrity; individuality; implication of influence.*

Keywords: *nature management, object, features and factors of formation, regional system, ecology, natural resources, functioning of the regional system, urbanization.*

The issues of interaction between nature and society have been in the centre of attention of scientists from different fields of knowledge since ancient times: from general theoretical problems of the universe (dialectics and cause-and-effect relations) and social development to narrow issues of interaction of individual components of the natural environment or the impact of different industries and activities on natural complexes, individual components of interaction. However, nature management as an independent scientific discipline was formed only in the second half of the XX century. The theoretical foundations were formulated by Yu.N.Kurazhkovsky, he saw the main tasks of this discipline in ‘the development of general principles of any activity related either to the direct use of nature and its resources, or with changing impacts on it’ [7].

The study of nature management has been and remains one of the main tasks of modern geography. According to some scientists, ‘nature management is a special-geographical, i.e., geographically bound, aspect of the interaction between nature, society and economy, forming the distribution of population on the Earth, its settlement (ekistics), the main life-support systems, regularities and evolution of the so-called territorial communities of people’ [4]. It represents a special sphere of human activity, reflects the relationship between the economy, settlement, production and social infrastructure and the natural environment. V.S.Preobrazhensky [11] believes that nature management is a process of interaction between man (society) and the natural environment or a sphere of activity aimed at the integrated solution of three main tasks: resource supply, preservation of people's living environment, and protection of natural diversity. Other scientist S.B.Potakhin, [10] consider nature management more narrowly, as a process of human consumption of natural (landscape) potential of the territory. Currently, two directions interact in nature management: 1) resource use – use, development, reproduction, improvement of natural resources; 2) protection of the environment and natural systems, i.e. preservation and improvement of environmental quality, protection of the gene pool, wealth and diversity of nature.

The authors believe that nature management is an actively developing sphere of human activity associated with the exploitation of natural resource potential of the region's territory, its protection and reproduction of natural resources. It should be noted that nature management from the position of determining its role and place in the process of social reproduction refers to both the sphere of material production and the infrastructure of production and social purposes, for the purposes of satisfying environmental, material and cultural needs of society. In foreign literature ‘nature management’, denoted by the term ‘land use’ is nowadays more and more often explained as ‘nature management’. Natural resource use is the process of utilisation of natural resources by society for a given historical moment.

In the definition of the term by Yu.N. Kurazhkovsky ‘...the tasks of nature management as a science are summed up to the development of general principles for the carrying out of all activities related either to the direct use of nature and its resources, or with changing its effects, the ultimate goal of this development is to provide a unified approach to nature as a universal basis of labour’ [7].

The object of nature management as a science is a complex of relationships connecting natural resources, living conditions of society and its socio-economic development. The subject of nature management can be considered the optimisation of these relations, the desire to preserve them and reproduction of living environment [12]. At present, nature management is at the stage of its development, when ‘qualitatively new tendencies in the relationship between social production and the environment are manifested. Nature protection becomes a necessary, but not sufficient condition for the harmonious development of nature’. We need a wide range reproduction of natural goods in the practice of nature management, i.e., purposeful activity to maintain or increase the ecological or natural potential of the environment [8].

Nature management is considered in a broad and narrow sense of the word. We will not consider in detail the category of ‘nature management’ as a system-wide sphere of activity, the conceptual apparatus of which is complex. The understanding of this definition depends on the field of interest of the researcher and the object of specific study. The authors consider regional nature management, i.e. a specific process of interaction of the economy and population of a given region with natural factors of its environment. Therefore, the main features of regional nature management are highlighted:

– every regional system, when developing, is affected by the natural-historical unity as an integrity; region as a result of the evolution of the natural environment of the territory and the population living on it, undergoes a number of changes, due to natural-economic and national-ethnic reasons;

– individuality – each region is individual by its physical and geographical characteristics (a region is a group of natural complexes characterised by a certain range of natural components (conditions and resources) and the nature of their use, treatment, reproduction, and by the level of socio-economic development and national-ethnic peculiarities of formation and development;

– bringing in the impact of regional systems of higher rank and neighbouring regions, material and informational transboundary transfers. The nature of the impact can be very diverse: economic, environmental, national-ethnic and political, etc. [5]. B.M. Ishmuratov and his authors speak about the regional character of nature management [4]. They define regional nature management as ‘a set of algorithms (or stereotypes) of use as reproduction of natural and socio-economic resources, united by belonging to a particular territory, serving as the basis for the formation of local communities of people, including the formation, development and reproduction of ethnic groups or nationalities [4].

Regional nature management as a system is formed and functions under the influence of internal and external factors. External factors include the geopolitical position of the region under study: the presence of external borders, historical economic and other ties with neighbouring countries and territories that do not share common borders with the region, as well as the region's place in the internal division of labour.

The internal factors of formation and functioning of the regional system include natural, socio-economic, historical, national, ethnic factors that differentiate separate territories of the region. These factors have a system-forming and structuring character. Their role changes in time and space. For example, natural factors in the past and present had a important system-forming significance, while their role in different periods of economic development of different industries is not the same. The highest role of natural factors is in the sectors related to the natural environment (natural resource and landscape use industries). This role has both direct and indirect character. The direct impact of natural factors involves the extraction of natural resources and their use in economic turnover. Indirect or secondary impact of natural factors is carried out either through the use of certain phenomena or natural forces in technological chains without their direct consumption, or through the pollution of natural environments by the discharge (emission) of harmful substances and unprocessed wastes. The importance of natural factors also depends on the level of development of productive forces in a particular region, on the nature and intensity of impact (extensive or intensive type) on the environment.

Economic factors of formation and functioning of the regional system and its individual subsystems are also determined by the level and focus of economic development; territorial and industrial structure of production and infrastructural arrangement of the territory; degree and kind of development, urbanisation of the region; provision with natural, economic, labour, intellectual and other resources. Economic factors have diverse and intensive action. The role of these factors is different at each stage of development of productive forces and production relations and depends on time priorities and targets. At present, the most significant economic factors for the majority of Russian regions include the existing territorial and industrial structure of the economic complex, the possibilities of its adaptation to the market economy or diversification, taking into account the previously accumulated material, intellectual, economic and social potential.

One of the most important factors of economic development during the transition to a market economy is the formation of modern market infrastructure, which has a complex character. Its formation is aimed at the creation of modern transport and information communications, engineering and technical arrangement of the territory, creation of a network of financial institutions. An important place in the system of market infrastructure is given to the creation of a network from organisations engaged in the provision of marketing services to domestic and foreign producers, providing material and technical supply and management of markets for manufactured products [1].

Social factors in the functioning of the regional system include various indicators of demographic development: the sex and age structure of the population; the ratio of births and deaths, including by age, with the separation of child mortality and mortality of persons of working age for various reasons from different categories of diseases, including those of a social nature. Social factors also include indicators of the availability and quality of labour resources: the number of persons of working age and the economic workload on them, which takes into account how many persons there are younger and older than working age per worker, and the social and qualification structure of the population. An important differentiating role is played by the national-ethnic structure of the population and peculiarities of settlement of the territory, which influence the subsequent character of the region's development – national priorities of lifestyle, activities, etc. Parameters reflecting the development of social infrastructure: the availability of social and cultural facilities, consumer demand for services of this kind, territorial aspects of the location of infrastructure facilities are also considered the social factors of public development. At the same time, it should be noted that while there is a certain growth in the development of market infrastructure, including production, information and financial services, and the provision of services for the sale of products in modern Russia, the market of social services is in an even deeper crisis than the economy as a whole.

Historical factors are important at the stage of formation and functioning of regional systems. They characterise the current economic development and settlement of the territory. At the same time, the role of certain factors is not the same at different stages of historical development of the territory [3; 6].

Ecological factors in the formation of regional systems are mainly associated with the identification and the need to take into account the parameters characterising the ecological capacity [2; 9] or, in another version, the carrying capacity of the territory. This indicator is constantly identified with the self-purifying capacity of the territory, which in our opinion is not legitimate, since the latter is determined by the ability of the territory to restore or reproduce itself, its physical and consumer properties. Ecological capacity or carrying capacity of the territory is a category of a higher order, allowing to determine what anthropogenic load the given territory is able to withstand, to process without its qualitative change. To determine the numerical value of the amount of ecological capacity N.B. Popova proposed the category of ‘ecological technocapacity, which is the maximum technogenic load, numerically not exceeding the variation of components of the natural environment in natural conditions and functioning’ and the algorithm for its determination on the basis of the energy approach [9]. All the above-mentioned environmental parameters are determined by the natural component of the territory, by its individual combination of natural conditions and resources. Environmental factors also include the indicators of regional development related to the location of environmentally intensive industries, the effects of population concentration, summation and synergy of various types of pollution, and this is already the result of economic, introduced impact on the environment.

Regional nature management is effective if its functioning results in maximum efficiency at economically and environmentally acceptable costs. As a criterion of economic acceptability of costs it is proposed to consider the outstripping rates of growth of production volumes against the rates of growth of resource costs for its production. The criteria of ecological acceptability of costs for the implementation of measures related to the use of natural resources differ depending on the reproducibility of any resource involved in the turnover, as well as the possibility of using secondary raw materials. For reproducible natural resources, such an indicator can be the ratio of the rate of their use and reproduction, for non-reproducible ones, that is the ratio of the rate of extraction of natural resources and production of finished products from them. Regional nature management consists of separate subsystems. Agrarian and industrial nature management, forest and water management are the most common, typical for all regional systems. The role of these subsystems changes in different regional systems depending on the combination of natural-ecological and socio-economic conditions of their development.

CONCLUSIONS

The given analysis of nature management has allowed to reveal that the processes of interaction between nature and society are the basis for the development of modern economy. This interaction is carried out in the process of regional nature management and characterised by the following features: natural-historical unity and/or integrity; individuality; brought impact. Territorial type of nature management is spatial and temporal differentiation of regional systems to ensure economically efficient and ecological development. Running of regional nature management systems is ensured by their internal properties and adaptation to changing natural-ecological and socio-economic conditions.

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ИЗУЧЕНИЕ ПРОЦЕССОВ РОСТА ЯСЕНЯ МАНЬЧУЖРСКОГО ПО МАТЕРИАЛАМ ГОСУДАРСТВЕННОЙ ИНВЕНТАРИЗАЦИИ ЛЕСОВ

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Хвойно-широколиственные леса в южной части Дальнего Востока – уникальная коллекция древесных пород, оставшаяся нам с третичного периода. Здесь произрастет множество редких семейств, родов, видов. Ярким представителем семейства Маслиновые (Oleaceae Hoffmgg.et Link) является род ясень (Fraxinus L). Род представлен ясенем маньчжурским (F. mandshurica Rupr.). В естественных условиях образует ильмово-ясеневые, а иногда ясеневые уремы. Ясень маньчжурский растет в составе хвойно-широколиственных лесов, встречается как одиночными экземплярами, так и небольшими группами. Одной породы насаждения не образует. В некоторых выделах его доля может достигать 40 % от общего запаса насаждения. Максимальный возраст отдельных деревьев достигает 200 и более лет, высота – 25–30 м, диаметр – до 1,0 м. Стволы прямые, полнодревесные, крона ажурная, кора гладкая. Требователен к плодородию почв. На хорошо дренированных почвах показывает высокую скорость роста, особенно в молодом возрасте.

Как следствие, количественная спелость в насаждении наступает в 40 летнем возрасте, техническая – в 80 лет. Обладает высокой зимостойкостью, что обеспечивает ему преимущества по сравнению с другими породами при лесоразведении в северных районах. Декоративен, переносит обрезку кроны в городских посадках. Нормативная база, составленная для этой породы, включает таблицы хода роста, объемные, сортиментные и товарные таблицы. Таблицы хода роста, составлены для трех типов леса и характеризуют динамику таксационных показателей в интервале 10–100 лет. В настоящей статье по материалам государственной инвентаризации лесов была построена таблица хода роста для ясеня маньчжурского. Экспериментальным материалом послужили 121 модельное дерево ясеня маньчжурского. Средние значения высот, диаметров и запасов выравнены с помощью параболы 2-го порядка. В таблице хода роста рассчитана динамика средних значений таксационных показателей: высоты, диаметра и наличного запаса.

Определен выход крупной плюс средней деловой древесины. По этим данным установлен возраст количественной и технической спелостей леса. Учитывая высокие продукционные характеристики ясеня маньчжурского, разработанный норматив можно считать дополнением к имеющейся нормативной базе, что важно при интенсификации лесохозяйственного производства в регионе. Таблицу можно использовать для оценки и прогноза запасов древесины в насаждениях с участием ясеня маньчжурского.

Ключевые слова*: ясень маньчжурский, таблица хода роста, смешанное насаждение, средний прирост, количественная и техническая спелости.*

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STUDY OF THE GROWTH PROCESSES OF THE MANCHURIAN ASH TREE BASED ON THE MATERIALS OF THE STATE FOREST INVENTORY

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Coniferous-deciduous forests in the southern part of the Far East are a unique collection of tree species left to us from the tertiary period. Many families, genera and species grow here. A prominent representative of the Olive family (Oleaceae Hoffmgg.et Link) is a genus of ash (Fraxinus L). The genus is represented by Manchurian ash (F. mandshurica Rupr.). In natural conditions, it forms ilmovo-ash, and sometimes ash uremes. Manchurian ash grows as part of coniferous-deciduous forests, occurs both in single specimens and in small groups. It does not form one type of plantings. In some allotments, its share can reach 40 % of the total stock of planting. The maximum age of individual trees *reaches 200 years or more, height is 25–30 m, diameter is up to 1.0 m. The trunks are straight, full-timbered, the crown is openwork, the bark is smooth. It requires fertile soils. On well-drained soils, it shows a high growth rate, especially at a young age.*

As a consequence, quantitative ripeness in the planting occurs at the age of 40, technical one occurs at 80 years. It has a high winter hardiness, which provides it with advantages over other species in afforestation in northern areas. It is ornamental and tolerant of crown pruning in urban plantings. The regulatory framework compiled for this species includes growth progress tables, volumetric, assortment and commodity tables. Growth progress tables are compiled for three types of forests and characterize the dynamics of taxation indicators between 10 and 100 years. In this article, based on the materials of the state forest inventory, a growth progress table for Manchurian ash was constructed. The experimental material included 121 model Manchurian ash trees. The average values of heights, diameters and reserves are equalized using a parabola of the 2nd order. The dynamics of the average values of taxation indicators is calculated in the growth progress table: height, diameter and available stock.

The output of large plus medium-sized business timber has been determined. According to these data, the age of quantitative and technical ripeness of the forest has been established. The listed indicators reflect the dynamics of the average data for this forest-forming species. The accuracy of determining the stock is not less than 5%. Taking into account the high production characteristics of Manchurian ash, the developed standard can be considered an addition to the existing regulatory framework, which is important for the intensification of forestry production in the region. The developed tables can be used to assess and forecast wood stocks in plantings with the participation of Manchurian ash.

Keywords: *Manchurian ash, growth progress table, mixed planting, average growth, quantitative and technical ripeness.*

RELEVANCE OF THE ISSUE

The ash genus (Fraxinus L.) belongs to the Oleaceae family (Oleaceae Hoffmgg.et Link). These are large deciduous trees reaching heights of 25–30 m and diameters of up to 1 m [1]. In the Russian Far East, the Manchurian ash (F. mandshurica Rupr.) (Fig. 1) is widely distributed. This species has been well studied. Growth progress tables for three forest types have been developed for modal stands of Manchurian ash [11]. These are included in a regional reference guide [10] but are not part of the tables or models for growth dynamics and productivity of the main forest-forming species of Northern Eurasia [12]. The study focuses on the growth characteristics of Manchurian ash in mixed coniferous-deciduous forests of the Primorsky region, where its share exceeds 40 % in some areas [6].

Results show that high productivity is achieved in stands containing Manchurian ash, Korean pine, Ayansky spruce, and white fir.

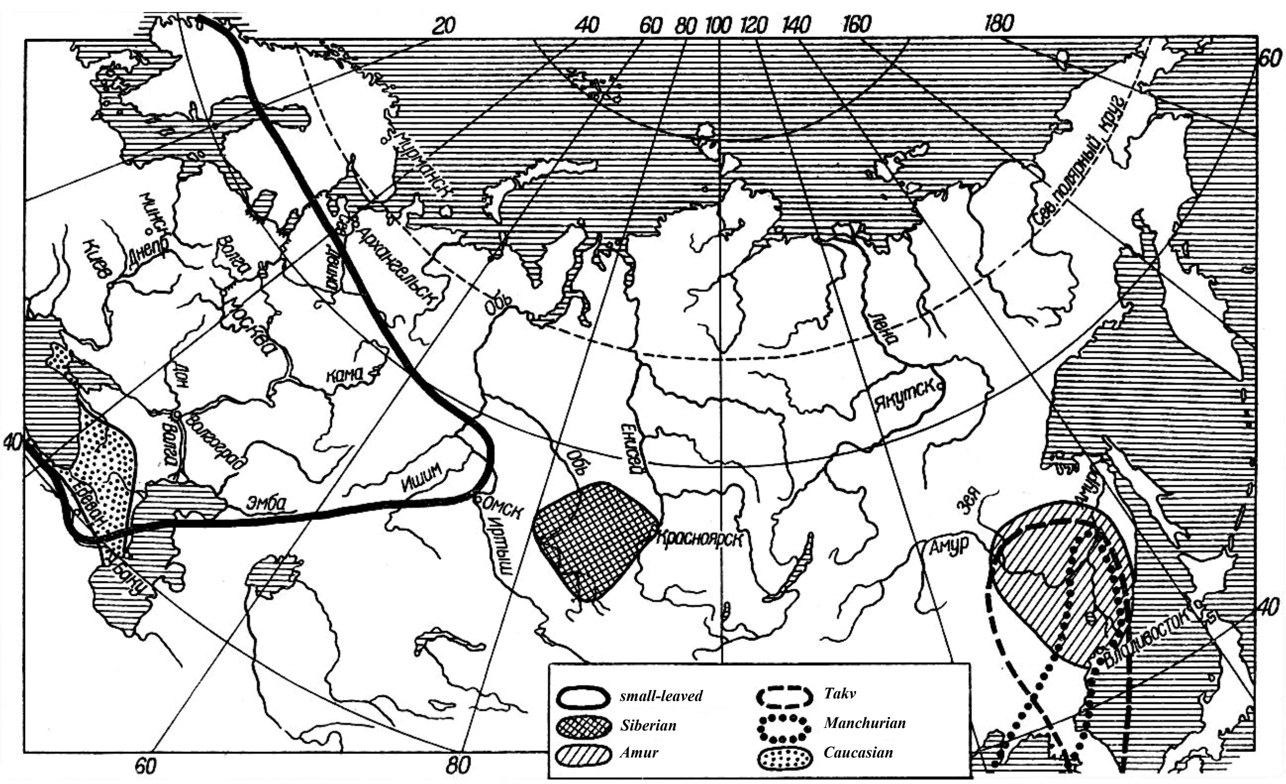

Fig. 1. Distribution of Ash Species

Manchurian ash is prevalent in the Primorsky and Khabarovsk regions, less common in the Amur region, and found on Sakhalin and Kunashir Islands [1; 14]. It grows in deciduous and mixed forests, not forming pure stands. Along with Maximovich poplar and Japanese elm, it forms elm-ash (urema) forests. The species can be found on slopes up to 700–800 m above sea level. It has a well-developed root system that provides wind resistance. When included in coniferous stands, it protects against windthrow [1]. The tree prefers fertile, moist soils and thrives on deep, well-drained alluvial soils underlain by sandy-gravel layers. It lives for over 200 years. Its crown is delicate, initially elongated-oval but becoming broad-rounded with age. The bark is gray or brownish, cracked, and 3–5 cm thick. The leaves are opposite, compound, and odd-pinnate. The flowers lack a perianth, and the fruits are single-seeded, oblong-elliptical samaras. It begins fruiting at 25–30 years [14]. Manchurian ash grows quickly, with young trees reaching a height increment of 1 meter per year under favorable conditions. Its wood is tough, hard, and attractive in texture and color. It is used in shipbuilding, mechanical engineering, construction (for interior finishing), furniture production, veneer, and plywood. The wood is in demand both domestically and internationally, making the species highly promising for forestry and processing. The aim of this study was to analyze the growth patterns of Manchurian ash in the Priamurye -Primorye coniferous-deciduous forest region based on national forest inventory data (NFI) and to develop a generalized growth progress table to determine the age of technical maturity

MATERIALS AND METHODS

The experimental material consisted of 75 permanent sample plots established in various strata during the state forest inventory in the Priamurye -Primorye coniferous-deciduous forest region [8]. The quantitative and qualitative indicators of Manchurian ash formation in the forest region were characterized by a sample of 121 Manchurian ash trees (Table 1). Since the plots were randomly located, the sample can be used to develop various forest taxation standards: growth tables, volume scaling rules, and standard tables of cross-sectional areas and stocks.

The use of model trees was based on their representation of a statistically significant part of the general population, which provides the necessary data for the entire population through measurements. The sample plots were selected based on the following criteria:

– Representativeness (ability to reflect the general population);

– Randomness (equal probability of selection for each object in the general population);

– Sufficient volume to ensure statistically significant results.

The accuracy criterion for forest accounting is the determination of total wood stock with an error margin of 3 %. For the Priamurye -Primorye coniferous-deciduous forest region, this margin was accepted as 3 %.

Table 1
Distribution of Manchurian ash trees by age and thickness steps

Thickness steps	Age, years																		Total
	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	
8	3	2																	5
12		1	1																2
16			3	3	1			2											9
20		1	1	2	1	6	2	3	1										17
24		1				3	5	2	3	1	1								16
28							1	4	6	6	1								18
32						1	2	1	2	5									11
36									1	6	6								13
40									1	1	6	3	2						13
44								1	1		7				1				10
48											2				1				3
52											1								1
56																		1	1
60																	1		1
64												1							1
	3	5	5	5	2	10	10	13	15	19	24	4	2	0	2	0	1	1	121

The sample covered an age range of 20–190 years, with an age variation within one thickness step reaching 90 years. SFI plots with continuous Manchurian ash coverage were not recorded, although small pure stands are found in river valleys [1].

The analytical review of the results of the NFI of the first inventory cycle for the forest area, prepared by FSBI Roslesinforg, provides a summary table reflecting the dynamics of average stocks of all tree species, including Manchurian ash. The dynamics were determined with 3% accuracy. These values serve as an average stock line for Manchurian ash stands in the Priamurye -Primorye coniferous-deciduous forest region. In order to determine the age changes of business timber, stocks were analytically levelled using a parabola of the 2nd row, then commoditized using local commodity tables [10] to determine the age of technical maturity [7]. In the final version, the growth progress table reflected the dynamics of heights, diameters and stocks. The latter is differentiated by the categories of business timber size. Calculation of Manchurian ash tree trunk volumes in bark and without bark when adjusting the volume discharge scale was carried out using regression equations, which are available in the handbook for forest inventory in the Far East [10]:

$$Vib. = 8,3 \times 10^{-5}dh + 310 \times 10^{-7}d^2h; \quad (1)$$

$$Vw.b. = 0,5 \times 10^{-5}DH + 281 \times 10^{-7}D^2H, \quad (2)$$

where Vib. – volume of Manchurian ash tree trunk in bark, м$^{3;}$ Vw.b. – trunk volume of Manchurian ash tree without bark m3; d – tree diameter, cm; h – step height, m.

When calculating other taxation indices, we used well-known formulae contained in the textbook of N.P. Anuchin [2].

RESEARCH RESULTS

The methodology of constructing growth progress tables for individual trees is tested on several tree species that are represented in the plantations as companion species [3-5; 15]. The theoretical basis for this methodological approach was the fact that a model tree grown in a forest environment was formed under the influence of many factors, but the determining factor was the intercenotic relations of trees of different tree species, their mutual influence on each other, which is subject to a certain regularity transmitted through the thinning constant [9; 13].

The mathematical expression of the thinning constant is the product of the number of stems by the average diameter to the degree of 1.5. Its biological meaning lies in the compensatory ability of the remaining trees to produce woody mass. The average value of the thinning constant determined by three tables of ash stands growth progress [11] is 86,000, or 8.6m^2 per tree.

The average values of heights and diameters calculated from the model trees are described by a parabola of the 2nd order (Fig. 2):

$$H = -0,189A^2 + 3,86A + 2,5, \quad R^2 = 0,88; \quad (3)$$

$$D = -0,025H^2 + 2,38H - 7,7, \quad R^2 = 0,67, \quad (4)$$

where H – height of the tree, m; D – diameter of the tree at a height of 1.3m, cm; A – age of the tree reduced by 10 times, years.

It should also be noted that the trees were randomly sampled, which excludes systematic error when describing age-related changes in taxation indices.

A similar equation describes the dependence of the stock on the age of Manchurian ash stands (Fig. 3):

$$y = -0,755x^2 + 33,92x - 24, \quad R^2 = 0,97, \quad (5)$$

where y – stock per 1 ha, m^3; x – age reduced by 10 times, years.

The height, diameter and available stock were summarised in the growth progress table (Table 2).

The available stock in the growth progress table was standardised according to the commodity tables [10]. For each age class, the dynamics of the average growth of large plus medium-sized business timber in percentage and absolute values was determined, and the age of the onset of quantitative and technical maturity was determined using these data.

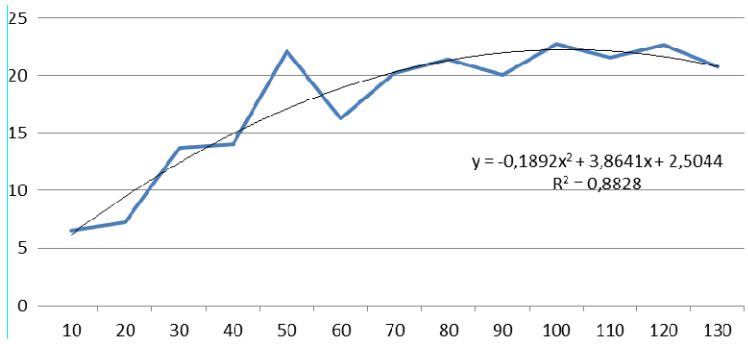

Fig. 2. Dependence of height on age of Manchurian ash tree

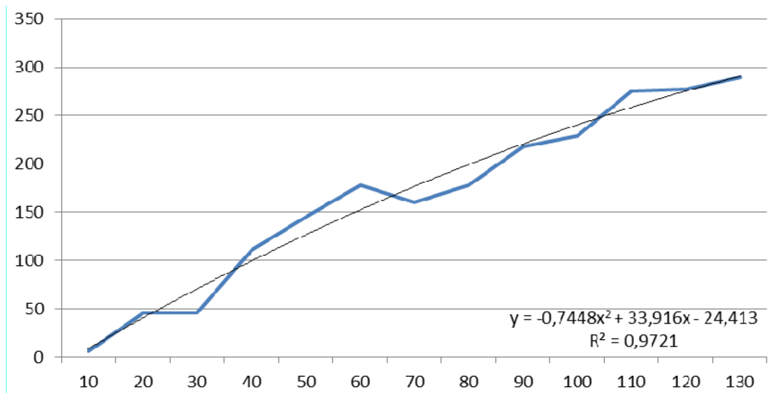

Fig. 3. Dependence of Manchurian ash stand stock on age

Table 3
Results of stock comparison with known analogues [11]

Age, years	Ash-alm urema				Sedge-grass				Swamp ash tree			
	Δav, m^3/ha	Mt	Mdt	Decl. %	Δav, m^3/ha	Mt	Mdt	Decl. %	Δav, m^3/ha	Mt	Mdt	Decl. %
10	0,4	40	9	–78	2,0	20	9	–55	1,4	14	9	–35
20	3,8	76	41	–46	2,4	48	41	–15	1,8	35	41	+15
30	3,4	101	71	–30	2,9	88	71	–19	1,9	56	71	+21
40	2,9	117	99	–14	3,3	131	99	–24	1,8	72	99	+27
50	2,6	129	127	–2	3,2	162	127	–22	1,7	87	127	+31
60	2,4	141	152	+7	3,2	190	152	–20	1,7	101	152	+34
70	2,2	153	177	+14	3,1	215	177	–18	1,6	115	177	+35
80	2,1	165	199	+17	3,0	237	199	–16	1,6	128	199	+36
90	2,0	177	221	+20	2,9	257	221	–14	1,5	138	221	+38
100	1,9	190	240	+21	2,8	275	240	–13	1,4	145	240	+39
Avg.				–10				–22				+27

Note: Mt – stock from the growth progress tables, m^3/ha; Md t – stock from the developed growth progress table, m^3/ha.

It is important to pay attention to the early onset of quantitative ripeness, which occurs at 40 years of age in the developed table. This is important when creating fast-growing plantations of deciduous species. In favourable conditions for growth, Manchurian ash shows a higher growth rate compared to other deciduous species.

The developed series was compared with the discharge table of Manchurian ash tree volumes. At the age of 20 years the height of ash tree corresponds to the 5th height category, and at the age of 100 years it corresponds to the 3rd height category. At the age of 100-130 years there is some slowdown of growth in height, which is reflected in the stock of stands. The main purpose of the growth progress table is to develop an averaged age series of taxation indices on the basis of which it is possible to determine the real age of technical maturity in the Priamurye-Primorye coniferous-deciduous region. The developed table has fulfilled its task.

CONCLUSION

A table of growth progress has been constructed for the Priamurye – Primorye coniferous-decidious forest region. Its analysis allows us to draw the following conclusions.

1. The age of quantitative ripeness in stands of Manchurian ash comes at 40 years, the age of technical ripeness at 60-80 years, which is 20 years earlier than the official cutting age in exploitation forests.

2. Comparison of the stocks of the developed table with the stocks of the known tables of the growth course did not reveal any significant discrepancies. The average value of the error did not exceed 5%.

3. The change of heights in the growth progress table differs from the discharge scale. In the initial ages it corresponds to the 5th discharge scale, but at 100 years of age it has changed to the 3rd discharge scale. On this basis it is concluded that the discharge scale should be recompiled to exclude systematic errors when calculating the reserves of plantations with Manchurian ash, prescribing management measures, etc. The comparison of the reserves of Manchurian ash forests with the developed table showed no significant differences.

4. The qualitative characteristics of Manchurian ash stands are not significantly affected by the age of model trees. Measurements of model trees recorded a weak tendency of increasing marketability class with increasing stand age.

5. The developed table can be used for calculations of business timber, the amount of damage caused by illegal logging, fire damage to plantations, and also as a kind of standard of long-distance stands, the accuracy of stock determination in which is not lower than 5 %.

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ОЦЕНКА СОСТОЯНИЯ СОСНОВЫХ ДРЕВОСТОЕВ В ГОРОДСКИХ ЛЕСАХ ГОРОДА ТЮМЕНИ (НА ПРИМЕРЕ ЭКОПАРКА «ЗАТЮМЕНСКИЙ»)

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Проанализирована устойчивость сосновых древостоев экопарка «Затюменский» с использованием показателей санитарного состояния, относительного жизненного состояния, относительной высоты и комплексного оценочного показателя. По большинству показателей состояние сосняков в зоне активного посещения оценивается как сильно ослабленное, в зоне умеренного и слабого посещения – как ослабленное. В ходе исследований установлено, что усиление рекреационных нагрузок не только снижает количество здоровых, но и увеличивает долю сильно ослабленных и даже отмирающих деревьев. В частности, в зоне активного посещения наблюдается снижение доли здоровых деревьев в 7–9 раз при увеличении доли ослабленных и отмирающих в 2,5–5 раз по сравнению с зонами умеренного и слабого посещения. Анализ видов повреждений стволов деревьев показал, что наиболее часто встречающимися являются нагар на стволах деревьев, смолотечение и механические повреждения. Отмечается общая закономерность увеличения количества различных повреждений деревьев с увеличением рекреационного воздействия. Количество деревьев со смолотечением, плодовыми телами и механическими повреждениями в зоне активного посещения в 1,5–5 раз больше в сравнении с зонами умеренного и слабого посещения. В целях предотвращения деградации сосновых насаждений экопарка «Затюменский» и повышения их устойчивости предложен ряд лесохозяйственных мероприятий, в частности, временное огораживание лесных участков находящихся в критическом состоянии на период их восстановления; проведение ландшафтных рубок с целью омоложения древостоев и созданием рекреационно привлекательных устойчивых ландшафтов полуоткрытого типа и т. д.

Ключевые слова: *городские леса, сосновый древостой, рекреационное воздействие, жизненное состояние древостоев.*

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ASSESSMENT OF PINE VITAL STATES IN THE URBAN FORESTS OF THE TYUMEN CITY (ON THE EXAMPLE OF ZATYUMENSKY ECOPARK)

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The assessment was given regarding the vital state of the pine forests in the Zatyumensky Ecopark based on indicators of the sanitary and vital status, relative height and a comprehensive assessment indicator. According to majority of indicators, the vital state of pine forests in the zone of active visits is assessed as severely weakened, in the zone of moderate and weak visits – as weakened. Common pattern of an increase in the number of severely weakened and dying trees and a decrease in the number of healthy trees with an increase in recreational impact has been observed. In particular, there is a decrease of healthy trees by 7–9 times in the zone of active visits with an increase of weakened and dying trees by 2.5–5 times compared to the zones of moderate and weak visits. The analysis of tree trunk damage types showed that the most common types are tree scorch marks, resin flow and mechanical damage. Common pattern of an increase in the number of tree damages with an increase in recreational impact has been observed. It was found that the in the zones of active visits the number of trees scorch marks on tree trunks, wood-destroying fungi and with mechanical damage is 1.5–5 times more compared to the zones of moderate and weak visits. In order to prevent degradation of pine plantations of the Zatyumensky Ecopark and increase their sustainability, a number of forestry measures are proposed, in particular, temporary fencing of forest areas in critical condition for the period of their *restoration; landscape felling to rejuvenate stands and create recreationally attractive sustainable landscapes of semi-open type, etc.*

Keywords: *urban forests, pine forests, recreational impact, vital state of forest.*

INTRODUCTION

Studying the peculiarities of recreational forest use is currently important for the scientific world and for the formation of strategic directions in ecology for the regions of the Russian Federation (Kazantsev et al., 2009; Zhamurina, Samokhvalova, 2016; Kazantseva, 2016; Sedykh et al., 2017). In the situation of increasing urbanisation of city areas, recreational forest management acquires special relevance, consisting in unique opportunities for recreation and restoration of physical and emotional strength of a person in the immediate vicinity of the place of residence in forest parks and artificial green spaces created within urban areas. Trees and shrubs not only clean the air and release oxygen, but also attract birds, making a natural environment most favourable for visitors. It is no wonder that forest parks have long been a place for family holidays.

At the same time, public visits to forest parks cause certain problems related to the reduction of sustainability and recreational attractiveness of plantations. The latter is particularly evident in the case of insufficient development of forest parks.

The impact of recreational users on forest plantations is determined by the following main factors: disruption of forest litter, trampling of seedlings, small undergrowth and living ground cover, collection of the most ornamental plant species, soil compaction, increased risk of fires, damage to trees and shrubs, which subsequently leads to their contamination with fungal spores, pollution by household waste (Isayeva et al, 1991; Zalesov et al., 2008; Sobolev et al., 2011; Mikhailova et al., 2021; Kolyada et al., 2022).

Logically, the degree of negative impact depends on many factors. The preservation of all components of plantations is facilitated by the creation of a well-thought-out road and path network, recreation areas and, of course, the regulation of visitors. The latter can be ensured by spreading them across the territory and concentrating them in the most stable areas.

Special attention is paid to the degradation of forest ecosystems. The latter starts under the influence of spontaneously formed paths and roads, which lead to the violation of the original integrity and structure of forest plantations, modification of the ground cover, partial reduction of the species composition of plantations, etc. (Mamaev, Koltunova, 2003; Timashchuk, Potapova, 2016; Dancheva, 2018; Gryazkin et al., 2020).

In order to control the condition of plantations in forest parks and prevent their degradation, it is necessary to carry out environmental monitoring based on silvicultural methods (Franklin, 1988; Debort, Meyer, 1989; Sobolev et al., 2011; Dancheva et al., 2014; Kazantseva, 2016). The combination of these methods allows to detect negative trends in the state of forest communities promptly and take appropriate measures to restore and rehabilitate plantations. Woody vegetation is one of the reliable indicators of the state and fixation of changes occurring in the natural environment. Therefore, monitoring of forest stands in combination with analyses of the condition of other components of forest plantations, provides reliable data on the changes occurring in recreational forests.

The recreational impact on the stand for pine forests of the Zatyumensky Ecopark is studied insufficiently, which determines the importance of this issue. The lack of sufficiently complete and up-to-date information on the peculiarities of recreational forest management in the state of urban forests of Tyumen served as a basis for scientific research in this direction.

The aim of the study is to assess the current state of pine stands in the Zatyumensky Ecopark of Tyumen city and to develop proposals to improve their sustainability and recreational attractiveness.

MATERIALS AND OBJECTS OF RESEARCH

Zatyumensky Ecopark is the second largest forest park, which is a part of the urban forests of Tyumen (Official..., 2022). The great success of the park is connected with its developed modern structure, equipment with all necessary elements of development (walking and cycling road network, recreation areas, lighting elements, sports grounds, dog walking areas, etc.).

Before 1960, the Zatyumensky Ecopark was an ordinary forest area, which was attached to the estate of merchant Ivan Petrovich Kolokolnikov (Ecopark..., 2022).

In 2017, the park was renovated and improved. A year later, the Zatyumensky Ecopark welcomed its first visitors.

The current state of the Zatyumensky Ecopark is characterised by its location within the Kalininsky administrative district of Tyumen on its outskirts in the western part of the city. The northern border is 1060m long, the eastern border is 705m long, the southern border is 1439m long, the western border is 585m long. The total area of the natural territory is 77.2 hectares. Geographical coordinates of the centre point of the ecopark are 57009'43‘’N; 65027'56‘’E.

The climate of the city Tyumen is moderately continental (Kozin, Bakulin, 1996). In spite of unstable weather and minimum air temperatures in December, reaching minus 42 ºC, it is possible to organise recreation in forest parks at any time of the year.

According to the forest-steppe zoning, the territory of the Ecopark belongs to the West Siberian sub-taiga-forest-steppe region of the forest-steppe zone (Special Protected Natural Areas of Russia, 2022). The landscapes of Tyumen are characterised by gentle, somewhat hilly plains, representing combinations of such cenoses as: pine-birch forests, birch broad-grass forests, spruce-fir forests and some groups of pine forests (Ivanenko, Kulyasova, 2008).

Forest plantations of the Zatyumensky Ecopark belong to the protective forests, the category is urban forests (Special Protected Natural Areas of Russia, 2022). Pine stands predominate by composition up to 58 % of the total forest area. The largest share of pine stands is characterised by I and II classes of bonitet. The average age of pine stands is 65 years. The following species are in the undergrowth of pine stands: species of the genera rosehip (*Rosa* L.), hawthorn (*Crataegus* L.), raspberry (*Rubus* L.), willow (*Salix* L.), cherry (*Padus* Mill.). The grass cover is represented by herbs.

The object of research was pine forests of natural origin of IV age class. To assess the state of stands, the indicators of sanitary state, vital state and relative height were used (Dancheva, Zalesov, 2015; Bun'kova et al., 2020). The categories of sanitary state of coniferous species vary from 1 to 5, where 1 is the characteristic of healthy trees (without signs of weakening), and 5 is the characteristic of dead trees. For each species of woody vegetation, the average value of the sanitary state category indicator was calculated based on the number of trees of each species (Cs).

The analysis of sanitary state was based on the average values of sanitary state categories Cs. Healthy, weakened and severely weakened stands had Cs values of 1.0–1.5; 1.51–2.5 and 2.51–3.5, respectively. Dying and dead stands had values of 3.51–4.5 and 4.51 and more.

An important indicator is the vital state of trees, which is determined by the state of the assimilation apparatus. If the latter was damaged by 20 % or less, the trees were classified as healthy, if 21–50 %, the trees considered as damaged (weakened), if 51–80 %, the trees were severely damaged, and if more than 80 %, the trees were classified as destroyed. Similar indicators were taken into account for stand assessment, but average indicators were taken into account.

The ratio of tree height to its cross-sectional area at a height of 1.3m was used to determine the Complex evaluation indicator (CEI). The optimum value of CEI for pine stands aged 40–70 years was considered to be 5-8, at the age of 80 years it was 4, and at the age of 100 and more years it was 2–3cm/cm^2.

The relative height index (H/D) was calculated as the ratio of tree height (m) to tree diameter (cm). If the H/D value exceeded 100, the state of trees was assessed as weakened.

The main taxation indices of trees were determined using standard methods (Dancheva, Zalesov, 2015).The obtained data were processed by generally accepted statistical methods using Excel programmes.

In order to assess the state of pine stands, 3 temporary sample plots (TSPs) were established with counting of all trees on them. The principle of their remoteness from the places of mass recreation (in our case, a linear object is a landscaped road for pedestrian and bicycle traffic) was taken into account when laying the plots according to the previously developed methodology (Dancheva, 2018). TSP-1 is laid at a distance of 10m from the object and assigned to the zone of active visits. TSP-2 is laid at a distance of 30m and assigned to the zone of moderate visits and TSP-3 is laid at a distance of 80m from the linear recreation object and assigned to the zone of low visits (control one).

According to a set of diagnostic features, including the proportion of the soil removed to the mineral layer, the character of herbaceous-shrub vegetation and undergrowth distribution over the area of the plot, according to the methodology of N.S. Kazanskaya, V.V. Lanina and N.N. Marfenin (1977), the stages of recreational digression of pine forests in each temporary sample plot were determined. On TSP-1 (zone of active visits), the part of the surface of the plot removed to the mineral layer was 19 % of the total area. There is a clustered location of undergrowth near the trunks of trees on the plot, live ground cover with predominance of cereals is located in places between paths, which corresponds to the IV stage of recreational digression. At TSP-2 (zone of moderate visits), the share of paths (the part of the plot surface removed to the mineral layer) was no more than 3 per cent (stage II of recreational digression). There were no paths at TSP-3 (zone of low visits), that corresponds to the first stage of digression.

RESEARCH RESULTS

Table 1 presents the average values of the main taxation and state indicators of pine forests of the Zatyumensky Ecopark depending on the intensity of recreational impact.

The research objects are represented by pure pine forests of I and II classes of bonitet. According to the indicator of relative completeness, the stands on all sample plots are highly complete.

During the research it was found that the values of average height and diameter indices on TSP-1 are 5–20 % lower than on the plots laid in the zone of moderate visits (TSP-2) and in the control one (TSP-3).

No clear dependence of the proportion of dead trees on the intensity of recreation was found, which, in our opinion, can be explained by the removal of dangerous trees. At the same time, the stand at TSP-1, where maximum recreational loads were recorded, is characterised as severely weakened according to the main state indicators (Cs, Relative vital state). Pine forests at TSP-2 and TSP-3 in the zone of moderate and low visits are weakened according to the analysed indicators.

The pine forests in all sample plots are stable according to the values of Complex evaluation indicator (CEI) and relative height (H/D).

According to the data of one-factor analysis of variance, reliable differences in height, diameter and relative vital state index are observed in most cases between pine stands at TSP-1 in the zone of active visits, TSP-2 and TSP-3 in the zone of moderate and low visits (Table 2). Reliable differences in the analysed indicators between pine stands at TSP-2 and TSP-3 were observed only in diameter.

The distribution of trees in the sample plots by vital state categories, presented in Table 3, shows an increase in the number of severely weakened and dying trees with increasing recreational impact. Thus, the number of such trees at TSP-1 in the zone of active visits is 17.7 %, which is 2.5–5 times higher compared to TSP-2 and TSP-3, located in the zone of moderate and low visits, respectively.

The opposite situation is observed when analyzing the healthy trees, the number of which decreases with increasing recreational impact. The proportion of healthy trees at TSP-1 in the zone of active visits is 3.2 per cent, which is 7–9 times lower compared to TSP-2 and TSP-3.

Table 1
Average values of taxation indices of pine forests depending on recreational impact

Indicator		TSP-1 (zone of active visits)	TSP-1 (zone of moderate visits)	TSP-1 (zone of low visits)
Stand composition		10Pines+Birch	10Pines	10Pines
Diameter, cm		28,7±0,9	35,9±1,6	29,8±0,8
Height, m		23,2±0,3	25,6±0,4	25,4±0,3
Completeness	absolute,m²/ha	32,9	35,5	43,0
	relative	0,8	0,8	1,0
Growth density,pcs./ha		469	330	580
Number of deadwood, pcs./ha		8	–	10
Reserves, m³/ha		337	413	485
Deadwood reserve, m³/ha		1	–	3
Bonitet class		II	I	I
Sanitary state category, Cs		2,8±0,1	2,2±0,1	2,3±0,1
Relative vital state, %		58,6±1,7	72,1±1,5	70,2±2,0
Complex evaluation indicator, cm/cm ^{2}		4,4±0,3	3,0±0,3	4,1±0,2
Relative height (H/D)		85,5±2,6	75,3±3,0	88,0±1,9

Table 2
Results of one-factor variance analysis of the main taxation indicators

Variance for the main taxation indicators		Comparable sample plots		
		TSP-1 and TSP-2	TSP-1 and TSP-3	TSP-2 and TSP-3
Diameter	F	16,8	0,7	13,8
	P	8,6	0,4	0,1
Height	F	22,9	26,3	0,18
	P	6,2	1,1	0,6
Relative vital state	F	26,6	19,4	0,4
	P	1,4	2,3	0,5
Fn		3,9	3,9	3,9

Table 3
Distribution of trees in sample plots by vital state categories, %

Temporary sample plots	Vital state category			
	dying	severely weakened	weakened	healthy
1	1,6	16,1	79,0	3,2
2	3,0	0,0	69,7	27,3
3	1,7	5,1	69,5	23,7

In the course of research, the relationship between the vital state of trees and their diameters was established. According to Fig. 1, severely weakened and dying trees are characterised by the smallest diameters. Healthy trees are characterised by the largest diameters.

The assessment of the degree of tree damage in different recreationally impacted functional zones showed that the most frequent damage is scorch on tree trunks. The share of trees with scorch on their trunks is up to 87 % of the total number of trees on the plot. The highest share of these trees was recorded on TSP-1 in the zone of active visits, and the lowest was on TSP-2 in the zone of moderate visits (Fig. 2).

The reason for scorching of tree trunks is running ground fires caused by burning poplar fluff and dry grass. Strengthened fire protection of the Ecopark has contributed to the fact that no forest fires have been recorded here for the last 3 years.

In addition to scorch on tree trunks, tar wounds, fruiting bodies of fungi and mechanical damage were observed on all plots. A general pattern of increase in the number of these damages with increasing recreational impact was established. Thus, the number of trees with tar wounds on TSP-1 in the zone of active visits reaches 31 %, which is 2-3 times higher compared to TSP-2 and 3. The number of trees with fungal fruiting bodies and mechanical damage on TSP-1 is 5 and 1.5 times higher than on TSP-2. There are no trees with fungal fruiting bodies and mechanical damage on TSP-3 in the zone of low visits.

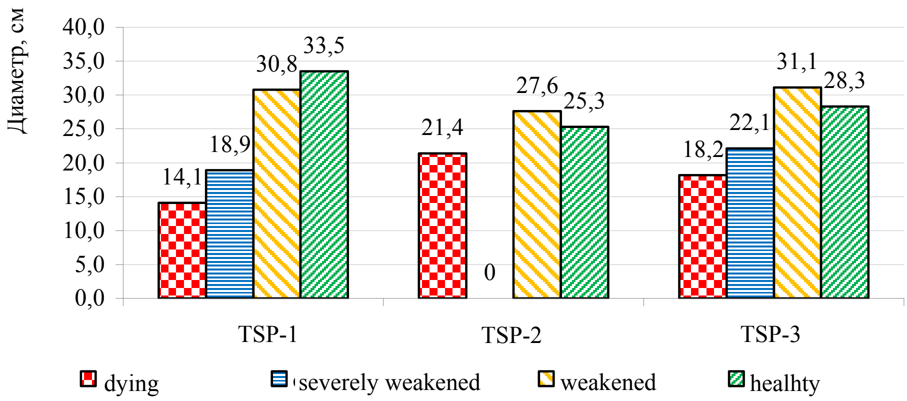

Fig. 1. Correlation between tree diameter and vital state category in pine forests of Zatyumensky Ecopark

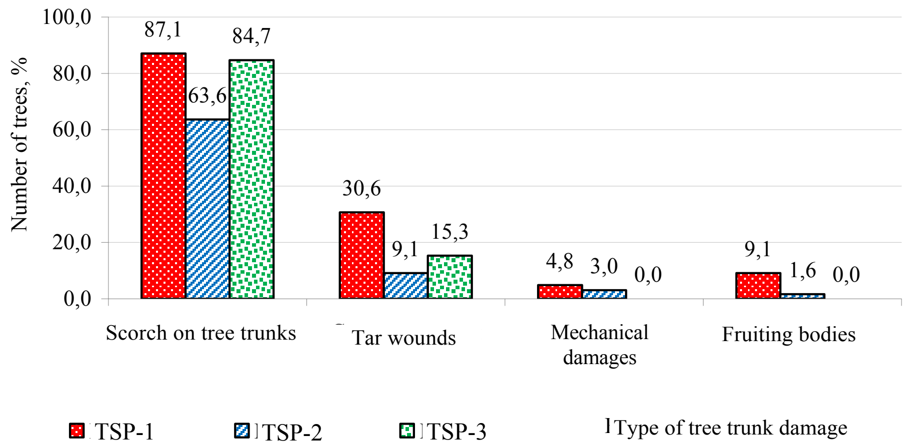

Fig. 2.Distribution of trunk damage types of pine trees on temporary sample plots

CONCLUSIONS

1. Pine forests on all sample plots are characterized as weakened according to the sanitary state indicator and relative vital state.

2. There is a general pattern of increase in the number of severely weakened and dying trees, as well as a decrease in the proportion of healthy trees with recreational impact. Weakened and dying trees at TSP-1 in the zone of active visits, constitute for an average of 18 %, which is 2.5–5 times more than at TSP-2 and 3 in the zones of moderate and low visits, respectively. The number of healthy trees at TSP-1 does not exceed 3.5 %, which is 7–9 times less than at TSP-2 and 3.

3. The most common types of tree trunk damage are scorch, tar wounds and mechanical damages. The most common tree damage in all sample plots is scorch.

4. There is a general pattern of increase in the number of various tree damages with increasing recreational impact. For example, the number of trees with tar wounds on TSP-1 is 2-3 times higher compared to TSP-2 and 3.

5. The number of trees with fungal fruiting bodies and mechanical damage on TSP-1 in the zone of active visits is 5 and 1.5 times higher than on TSP-2 in the zone of moderate visits. There are no trees with fungal fruiting bodies and mechanical damage on TSP-3 in the zone of low visits.

6. In order to prevent degradation of pine stands in the Zatyumensky Ecopark and to increase their sustainability, the following measures can be proposed:

– conducting temporary fencing of forest areas that are in critical state for the period of their restoration;

– redirecting the flow of visitors to more recreationally sustainable areas of the Ecopark;

– creation of natural curbs along the landscaped road and path net from Karagana tree, raspberry, rosehip, eastern thuja and other tree and shrub species, which will be a natural barrier for visitors;

– landscape cutting to restore stands and create recreationally attractive and sustainable landscapes of semi-open type with the involvement of various introduced trees.

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МОДЕЛИ ДЛЯ ОЦЕНКИ БИОМАССЫ ДЕРЕВЬЕВ ЛЕСООБРАЗУЮЩИХ ВИДОВ ПО ДИАМЕТРУ КРОНЫ В СВЯЗИ С ИСПОЛЬЗОВАНИЕМ ДРОНОВ*

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В связи с изменением климата и потенциальной возможностью его стабилизации с помощью управляемых лесов и оценки их углерод депонирующей способности, особую актуальность приобретает возможность оперативной оценки биомассы и органического углерода лесного покрова. В последние годы технологии дистанционного зондирования лесов на основе беспилотных летательных аппаратов (дронов) позволили получать значения параметров крон деревьев с максимально близкого расстояния, что обеспечивает не только высокую точность и скорость измерений, но и возможность различать деревья по видовому составу. В настоящем исследовании предпринята попытка разработки аллометрических моделей, предназначенных для оценки биомассы деревьев лесообразующих родов России по диаметру кроны. Для реализации поставленной цели исследования использована авторская база данных в количестве 15200 определений биомассы деревьев. Из нее отобраны 1665 модельных деревьев пяти хвойных и 780 модельных деревьев шести лиственных видов. Поскольку фактические значения биомассы деревьев представлены в базе данных несколькими викарирующими видами в пределах рода, анализ зависимости биомассы дерева от его диаметра кроны выполнен на уровне родов и подродов. Рассчитан пакет аллометрических моделей биомассы деревьев полного фракционного состава для каждого рода и подрода, все регрессионные коэффициенты которых значимы на уровне р < 0,001. Предложенные аллометрические модели могут быть использованы при оценках биомассы и органического углерода деревьев и древостоев лесообразующих родов России на основе цифровой фотограмметрии визуальных данных, получаемых с помощью дронов.

Ключевые слова: *биомасса деревьев, дистанционное зондирование полога, дроны, аллометрические модели.*

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MODELS FOR ESTIMATING BIOMASS OF FOREST-FORMING SPECIES BY CROWN DIAMETER AS RELATED TO DRONE INVOLVING

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Due to climate change and the potential possibility of its stabilization with the help of managed forests and assessment of their carbon depositing capacity, the possibility of operational assessment of biomass and organic carbon of forest cover becomes particularly relevant. In recent years, remote sensing technologies of forests based on unmanned aerial vehicles (drones) have made it possible to obtain the values of the parameters of tree crowns from as close distance as possible. That provides not only high accuracy and speed of measurements, but also the ability to distinguish trees by species composition. In this study, an attempt is made to develop allometric models designed to estimate the biomass of trees of forest-forming genera in Russia by crown diameter. To achieve the research goal, an author's database of 15200 definitions of tree biomass was used. A number of 1665 model trees of five coniferous and 780 model

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trees of six deciduous species were selected from it. Since the actual values of the biomass of trees are presented in the database by several vicarious species within the genus, the analysis of the dependence of the biomass of a tree on its crown diameter is performed at the level of genera and subgenera. A package of allometric models of the biomass of trees of full component composition for each genera and subgenera is calculated, all regression coefficients of which are significant at the level of p < 0,001. The proposed allometric models can be used to estimate the biomass and organic carbon of trees and stands of forest-forming genera in Russia based on digital photogrammetry of visual data obtained using drones.

Keywords: *tree biomass, remote sensing of the canopy, drones, allometric models.*

INTRODUCTION

In modern conditions, it is often necessary to estimate promptly the carbon storage capacity of plantations in some forest areas both at a given time and at certain time intervals. Photogrammetry methods based on aerial photography have made it possible to determine the size of tree crowns with greater accuracy than in ground-based taxation [2; 18]. Today, great prospects in this direction are opened by the use of unmanned aerial vehicles, or drones [3; 13; 17].

This study attempts to develop allometric models for estimating tree biomass of forest-forming genera in Russia based on crown diameter. It is assumed that by measuring crown diameter using drones it is possible to estimate tree biomass in forest plots quickly and with low labour input. A large set of allometric models and tables for estimating tree biomass from trunk diameter at breast height for different tree species in different countries is now available [15]. These models can be used to estimate tree and stand biomass by establishing relationships between trunk diameter and crown parameters estimated by digital photogrammetry [5].

MATERIALS AND METHODS OF RESEARCH

To realise the set goal of the study, 1665 model trees of five coniferous and 780 model trees of six deciduous species were selected from the formed database in the amount of 15200 determinations [16]. Since actual values of tree biomass are represented in the database by several vicariant species within genera, we analysed the dependence of tree biomass on crown diameter at the level of genera and subgenera. For some genera it was not possible to calculate the dependence of root biomass on crown diameter due to lack of data, and in such cases the average root to aboveground mass ratio was calculated for each genus. The experimental material was processed using the multivariate regression analysis in programme Statgraphics-19 (http://www.statgraphics. com/).

The following structure of the allometric model is adopted:

$$\ln P_i = a_0 + a_1(\ln Dcr), \quad (1)$$

where Pi is biomass of the i-th fraction in absolutely dry state, kg (trunk, branches, needles (leaves), aboveground and roots, respectively P_s, P_b, P_f, P_a and P_r); Dcr is a crown diameter, m. When calculating the models (1), their correction for logarithmic transformation was applied [6].

RESULTS AND THEIR DISCUSSION

The results of calculating model (1) are presented in Table 1. All regression coefficients of the models presented in Table 1 are reliable at the level of p<0.001, which ensures the reproducibility of the obtained results [8].

For genera (or subgenera) with insufficient representation of actual data on root biomass, average indices of relative root biomass Pr/Pa [4] are proposed (Table 2).

Table 1
Results of calculations for models (1)

Genera (or subgenera)	Dependent variable	Regression coefficients of model (1)		$adjR^{2**}$	SE***
		a_0*	a_1		
Coniferous genera (subgenera)					
Subgenus *Pinus* L. (two-needled pine)	$\ln P_s$	1,3728	3,1588	0,775	1,04
	$\ln P_b$	–1,0900	3,3297	0,862	0,82
	$\ln P_f$	–1,0441	2,6438	0,825	0,75
	$\ln P_a$	1,5231	3,1102	0,809	0,92
	$\ln P_r$	0,2914	2,1315	0,747	0,83
Picea L.	$\ln P_s$	–0,6877	4,2035	0,792	1,02
	$\ln P_b$	–1,3117	3,3039	0,816	0,74
	$\ln P_f$	–0,9527	2,7751	0,730	0,80
	$\ln P_a$	0,1182	3,7837	0,805	0,88
	$\ln P_r$	–1,6477	3,9079	0,859	0,77
Abies Mill.	$\ln P_s$	3,6862	1,3585	0,372	0,81
	$\ln P_b$	1,0775	1,7742	0,632	0,64
	$\ln P_f$	1,2636	1,3489	0,435	0,72
	$\ln P_a$	3,8127	1,4107	0,429	0,75
	$\ln P_r$	–1,2933	3,3717	0,651	0,81

End of Table 1

Genera (or subgenera)	Dependent variable	Regression coefficients of model (1)		$adjR^{2**}$	SE***
		a_0*	a_1		
Larix Mill.	$\ln P_s$	0,9429	2,9603	0,783	1,00
	$\ln P_b$	–1,1464	2,8661	0,905	0,59
	$\ln P_f$	–1,9992	2,3545	0,872	0,58
	$\ln P_a$	1,1248	2,8846	0,818	0,87
	$\ln P_r$	0,7476	2,2860	0,694	0,70
Subgenus *Haploxylon* (five-needled pine	$\ln P_s$	–0,1241	3,2871	0,791	0,88
	$\ln P_b$	–1,0706	3,0015	0,815	0,75
	$\ln P_f$	–1,2602	2,6026	0,843	0,58
	$\ln P_a$	0,3997	3,1351	0,828	0,75
	$\ln P_r$	–	–	–	–
Deciduous genera					
Betula L.	$\ln P_s$	0,8579	2,6037	0,790	0,84
	$\ln P_b$	–1,3154	2,8681	0,797	0,91
	$\ln P_f$	–1,9517	2,1248	0,768	0,77
	$\ln P_a$	1,0178	2,6137	0,801	0,82
	$\ln P_r$	1,5260	1,7772	0,666	0,65
Populus L.	$\ln P_s$	0,3936	2,7814	0,823	0,49
	$\ln P_b$	–2,6687	3,3665	0,839	0,60
	$\ln P_f$	–3,2737	2,7978	0,785	0,59
	$\ln P_a$	0,4242	2,8530	0,835	0,48
	$\ln P_r$	–	–	–	–
Tilia L.	$\ln P_s$	3,0110	1,5766	0,551	0,85
	$\ln P_b$	1,3755	1,2847	0,559	0,76
	$\ln P_f$	–0,4838	1,1621	0,563	0,68
	$\ln P_a$	3,2197	1,5153	0,560	0,80
	$\ln P_r$	–	–	–	–
Alnus Gaertn.	$\ln P_s$	3,0247	1,6498	0,455	0,91
	$\ln P_b$	0,2965	1,8645	0,578	0,85
	$\ln P_f$	–0,4115	1,2563	0,502	0,67
	$\ln P_a$	3,1164	1,6524	0,475	0,88
	$\ln P_r$	–	–	–	–
Salix L.	$\ln P_s$	–1,0895	3,1089	0,975	0,31
	$\ln P_b$	–2,5138	3,2841	0,964	0,38
	$\ln P_f$	–2,3712	2,1896	0,939	0,34
	$\ln P_a$	–0,7207	3,0777	0,990	0,18
	$\ln P_r$	–	–	–	–
Quercus L.	$\ln P_s$	0,8666	2,9430	0,704	1,09
	$\ln P_b$	–2,0350	3,5970	0,854	0,85
	$\ln P_f$	–2,5974	2,4818	0,852	0,59
	$\ln P_a$	0,8901	3,0291	0,744	1,01
	$\ln P_r$	2,4277	1,4565	0,814	0,40

Note. Here in after:
*The free term of the model is adjusted for logarithmic transformation [6];
**adjR^2- the coefficient of determination adjusted for the number of variables;
***SE - standard error of the equation.

Table 2
Average root to aboveground weight ratios for five genera (subgenera)

Indicator	*Haploxylon*	*Populus*	*Tilia*	*Alnus*	*Salix*
Pr/Pa	0,24±0,10	0,33±0,08	0,27±0,11	0,22±0,07	0,27±0,09

Then we calculated allometric models of the form

$$\ln D = a_0 + a_1(\ln Dcr), \qquad (2)$$

where D –is trunk diameter at breast height, cm. The results of the calculation of models (2) are presented in Table 3. Models (2) serve as an intermediate link when there is a need to use the constructed models (1) with known crown parameters obtained by digital photogrammetry to estimate tree biomass at local sites using appropriate local allometric models in which the independent variable is represented by trunk diameter at breast height [15].

Table 3
Results of calculation for models (2)

Genera (subgenera)	Dependent variable	Regression coefficients of model (2)		$adjR^2$	SE
		a_0	a_1		
Coniferous genera (subgenera)					
Subgenus *Pinus* (two-needled pine)	ln*D*	1,7295	1,0355	0,621	0,44
Picea	ln*D*	0,6686	1,7819	0,804	0,41
Abies	ln*D*	2,4659	0,5337	0,355	0,33
Larix	ln*D*	1,4623	1,0931	0,769	0,35
Subgenus *Haploxylon* (five-needled pine)	ln*D*	1,1484	1,2838	0,793	0,34
Deciduous genera					
Betula	ln*D*	1,2705	1,0250	0,791	0,32
Populus	ln*D*	1,0422	1,2074	0,850	0,19
Tilia	ln*D*	2,6741	0,3339	0,490	0,20
Alnus	ln*D*	2,1375	0,6572	0,458	0,36
Salix	ln*D*	0,7066	1,3175	0,981	0,11
Quercus	ln*D*	1,1187	1,1959	0,740	0,40

Numerous models similar to (2) are available in the literature for different tree species. Determination coefficients, which characterise the proportion of explained variability of trunk diameter through crown diameter, vary within a fairly wide range. For example, it is 0.909; 0.961 and 0.956 for fir, spruce and beech in Croatia, respectively [14], it is 0.762 for incense pine in the USA [12], it ranges from 0.610 to 0.870 for seven deciduous species in the USA [7], and it ranges from 0.560 to 0.870 for the other six deciduous species in the USA [10]. Coefficients of determination in our models (2) vary among genera from 0.355 to 0.981. But even with the lowest coefficient, e.g., in model (2) for linden or model (1) for fir, the regression coefficient of the model is significant at the level $p < 0.001$ ($t = 7.0–7.1 > t_{001} = 3.29$). The low coefficients of determination in some cases in our models (2) may be due to the wide spatial representation of species with a correspondingly high proportion of unaccounted 'noise'. At the same time, the high coefficients of determination of the three tree species in Croatia (0.90–0.96) can be explained by the fact that the models were obtained within one local site-national park, where 2,000 trees of each species were measured [14].

Tree mapping by drone from a minimum height makes it possible not only to determine crown diameters with great accuracy and speed, but also to identify tree species without errors, even such as spruce and fir, for example, by the opposite orientation of cones. While in saxaul forests representing open (sparse) tree plantations, determination of tree mass by crown diameter estimated by aerial photo interpretation was a common procedure [1], in closed stands a part of trees remains hidden under the main canopy, thus causing some underestimation of biomass [9]. The magnitude of this underestimation is proportional to canopy closure, and it is technically possible to make corrections as a result of a special study. In cases where the change in stand biomass over time is estimated by periodic overflights of the same plot, the probability of possible underestimation is significantly reduced or becomes comparable to the error in crown measurement.

The values of tree and stand biomass calculated by models (1) can be converted to the amount of carbon deposited in biomass by a ratio of 0.5 [11].

CONCLUSION

Thus, for the main tree genera and subgenera growing on the territory of Russia, a package of allometric models for estimating tree biomass by crown diameter has been proposed for the first time. All regression coefficients of the constructed models are significant at the level of $p < 0.001$, which ensures reproducibility of the obtained results. The use of unmanned aerial vehicles (drones) makes it possible to quickly and with little labour input to estimate tree biomass by recorded crown diameter, including, taking into account differentiation of the canopy by species composition.

The proposed allometric models can be used to estimate biomass and organic carbon of trees and stands of forest-forming genera in Russia based on digital photogrammetry of visual data obtained by drones.

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ВЫРАЩИВАНИЕ СЕЯНЦЕВ СОСНЫ КЕДРОВОЙ СИБИРСКОЙ С ЗАКРЫТОЙ КОРНЕВОЙ СИСТЕМОЙ НА ЭКСПЕРИМЕНТАЛЬНЫХ СУБСТРАТАХ

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Изучен вопрос выращивания сеянцев сосны кедровой сибирской с закрытой корневой системой на экспериментальных смесях на основе торфа. Основным компонентом субстрата был использован торф местного происхождения, добываемый в Козульском районе Красноярского края. Торф смешивали с опилками, вермикулитом, перлитом в разных пропорциях. В ряде экспериментальных смесей в качестве основного компонента вместо торфа был использован кокосовый субстрат. В качестве контрольного субстрата использовали торф производства компании ООО «ВЕЛТОРФ» по рецепту № 19с/1.

Проведенные исследования за ростом сеянцев сосны кедровой сибирской, выращиваемых с закрытой корневой системой в кассетах с различным составом субстратов позволили сделать ряд выводов: при использовании чистых торфов, целесообразно применение удобрений; полноценной заменой торфяным субстратам может служить кокосовый субстрат при условии смешивания его с вермикулитом в пропорции 50/50 %; имеет смысл обратить внимание на торфы местного происхождения для снижения себестоимости затрат.

Ключевые слова: *сосна кедровая сибирская, сеянцы, закрытая корневая система, субстрат, торф, кокосовый субстрат, перлит, вермикулит.*

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GROWING SEEDLINGS OF *PINUS SIBIRICA* DU TOUR WITH A CLOSED ROOT SYSTEM ON EXPERIMENTAL SUBSTRATES

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The issue of growing Pinus sibirica Du Tour seedlings with a closed root system on experimental mixtures based on peat has been studied. The main component of the substrate was peat of local origin, mined in the Kozulsky district of the Krasnoyarsk Krai. Peat was mixed with sawdust, vermiculite, and perlite in different proportions. In a number of experimental mixtures, coconut substrate was used as the main component instead of peat. Peat produced by VELTORF LLC was used as a control substrate according to recipe No. 19c/1.

Conducted studies of the growth of Pinus sibirica Du Tour seedlings grown with a closed root system in cassettes with different compositions of substrates allowed us to draw a number of conclusions: when using clean peat, it is advisable to use fertilizers; Coconut substrate can serve as a complete replacement for peat substrates, if mixed with vermiculite in a 50/50% ratio; It makes sense to pay attention to peats of local origin to reduce costs.

Keywords: *Pinus sibirica, seedlings, closed root system, substrate, peat, coconut substrate, perlite, vermiculite.*

INTRODUCTION

The use of planting material with a closed root system is a promising direction in silvicultural production [1; 2].

Modern forest restoration volumes require solving the problem of extending planting periods while maintaining potential survival rates. This can be achieved by using planting material with a closed root system.

Planting material with a closed root system has several advantages over the traditional seedlings and saplings used in domestic silvicultural production. Seedlings with a closed root system are well-suited for transportation, allow to extend the silvicultural season, and, according to several researchers, demonstrate better survival rates under unfavorable forest growth conditions [3].

Currently, active efforts are being made to reduce the cost of cultivating plants with a closed root system and to develop resource-saving technologies.

When creating forest plantations of Siberian pine using planting material with a closed root system, it is necessary to select the most productive type of substrate [2; 4].

Advanced greenhouse technologies are based on the specific properties of the substrate used and the optimization of the nutrient regime. The cultivation of tree seedlings in closed soil is mainly carried out on substrates composed of high-moor peat [6]. The basis for creating the most productive nutrient substrate for coniferous planting material with a closed root system is milled high-moor peat [1].

It is believed that a high-quality nutrient substrate consists of a mixture containing 60–70 % peat and various additives that support the physicochemical properties of the substrate for growing seedlings [9].

E.V. Titov [7] described in detail the technique of growing Siberian pine seedlings with a closed root system. This approach involves the use of peat, plastic, or other pre-prepared containers for seedlings, with a height of at least 8 cm and a volume of 200–300 cm^3. In mid-April, a substrate is prepared from a mixture of peat and loam (1:1), with fertilizers added at the following rates per 10 liters of mixture: granulated superphosphate – 50 g, potassium salt – 25 g, dolomite lime – 250 g. The containers are then filled with this substrate and placed on the soil in a greenhouse.

D.I. Mukhortov and A.V. Antropova [5] presented the results of studies on the agro-physical properties of various root-closing substrates, analyzing their impact on the growth and development of Scots pine seedlings grown in containers as planting material for reforestation projects. Their research confirmed that the growth and development of Scots pine planting material with a closed root system are more influenced by the agro-physical properties of the substrate than its agrochemical properties. Regression analysis of the correlation between the biometric parameters of seedlings and the water-physical properties of the substrate revealed an inverse correlation between dry matter mass and density. Substrate density has the greatest impact on the root collar diameter and dry matter mass of seedlings. The introduction of agroperlite into the substrate affects its agro-physical properties. With an increase in the proportion of agroperlite, the bulk density of the substrate increases by 55 %, and the density of the solid phase increases by 9 %, which is associated with an increase in the water retention capacity of the substrate.

The number of researches on the selection of optimal substrate compositions to replace peat fully is increasing. One such substrate is coconut fiber, which is characterized by its cation exchange capacity and optimal air-to-water ratio [8].

OBJECTS AND METHODS OF RESEARCH

The object of the study is seedlings of Siberian pine seedlings (*Pinus sibirica Du Tour*) grown with a closed root system in Plantek-81 trays on experimental substrate compositions in a greenhouse provided by Reshetnev University under an agreement with LLC "Krasnoyarsk Forest Nursery."

The seeds were collected in the North-Yeniseisk forestry, stratified in winter trenches, and sown in June 2022 in trays with dimensions of 38.5×38.5×8.0 cm.

As the control substrate was used peat produced by LLC "VELTORF" under recipe No. 19c/1. This peat mixture contains milled peat (50%), cut peat (30 %), limestone flour, agroperlite (20%), a wetting agent (pH aqueous solution: 4.0–4.5), and Pg Mix (1 kg/m^3) [10].

In the experimental mixtures, locally sourced peat from the Kozulsky district of Krasnoyarsk Krai, provided by LLC "KrasKIP," was used as the primary substrate component.

The peat was mixed with sawdust, vermiculite, and perlite in various proportions. In some experimental mixtures, coconut substrate was used as the main component instead of peat (Figure 1).

This study presents the results of seedling growth both without the use of fertilizers and with the application of AgroMaster 18.18.18+3 fertilizer.

RESULTS AND DISCUSSION

During the observation of the growth of Siberian pine seedlings, it was found that the average height of seedlings grown without the use of fertilizers by August 18, 2022, was 3.02±0.02 cm. Depending on the experimental variant, this parameter ranged from 2.6±0.09 cm to 3.43±0.07 cm. The variability level of the height parameter was classified as medium (Figure 2).

The best growth among the studied variants was observed in seedlings grown on a coconut substrate with the addition of vermiculite in a 50/50 proportion (variant 9). The differences with most other variants were statistically significant at a 95 % probability level.

Good height growth was also observed in seedlings from variants 5 (peat produced by LLC "KrasKIP" with the addition of sawdust and vermiculite in a 50/25/25 % ratio) and 6 (peat by LLC "KrasKIP" with sawdust and vermiculite in a 33.3/33.3/33.3% ratio).

Seedlings grown on substrates from variants 16 (peat by LLC "KrasKIP" with the addition of sawdust and perlite in a 50/25/25 % ratio) and 10 (coconut substrate with perlite and vermiculite in equal proportions) lagged in growth.

The next series of experiments included determining the role of the AgroMaster 18.18.18+3 fertilizer in cultivating Siberian pine seedlings on various substrates.

It was found that by 18.08.2022, the average height of seedlings grown with fertilizer application was 3.01 ± 0.02 cm. Depending on the substrate composition, this parameter ranged from 2.81±0.06 cm to 3.33±0.08 cm (Figure 3).

It should be noted that treatment of trays filled with experimental substrates with AgroMaster 18.18.18+3 fertilizer did not significantly affect seedling growth in most variants.

However, when using the peat mixture produced by LLC "VELTORF" with the addition of agroperlite (control variant 1) and peat by LLC "KrasKIP" (variant 2), the application of fertilizer increased significantly the height of Siberian pine seedlings. In the first variant, the height was 3.11±0.05 cm compared to 2.74±0.07 cm. In the second, the height was 3.22±0.08 cm compared to 2.93±0.08 cm. The differences were statistically significant (t_f = = 4.30 and 2.56, respectively, exceeding t_{05}) (see figure).

The application of fertilizer also affected positively the height of seedlings grown on substrates in variants 3, 10, and 16.

Figure 1
Experimental Substrate Variants

Variant number	Substrate	Proportions of the mixture, %
1	Peat mixture according to recipe No. 19c/1 produced by VELTORF LLC with the addition of agroperlite (control)	80/20
2	Peat produced by KrasKIP LLC	100
3	Peat produced by KrasKIP LLC with the addition of vermiculite	50/50
4	Peat produced by KrasKIP LLC with the addition of sawdust	50/50
5	Peat produced by KrasKIP LLC with the addition of sawdust and vermiculite	50/25/25
6	Peat produced by KrasKIP LLC with the addition of sawdust and vermiculite	33,3/33,3/33,3
7	Coconut substrate without additives	100
8	Coconut substrate with the addition of perlite	50/50
9	Coconut substrate with the addition of vermiculite	50/50
10	Coconut substrate with the addition of perlite and vermiculite	33,3/33,3/33,3
11	Peat produced by KrasKIP LLC with the addition of perlite	50/50
12	Peat produced by KrasKIP LLC with the addition of perlite and vermiculite	33,3/33,3/33,3
13	Peat produced by KrasKIP LLC with the addition of coconut substrate	50/50
14	Peat produced by KrasKIP LLC with the addition of sawdust and perlite	33,3/33,3/33,3
15	Peat produced by KrasKIP LLC with the addition of sawdust, perlite and vermiculite	25/25/25/25
16	Peat produced by KrasKIP LLC with the addition of sawdust and perlite	50/25/25

Figure 2
Height of Siberian cedar pine seedlings grown without fertilizers, cm

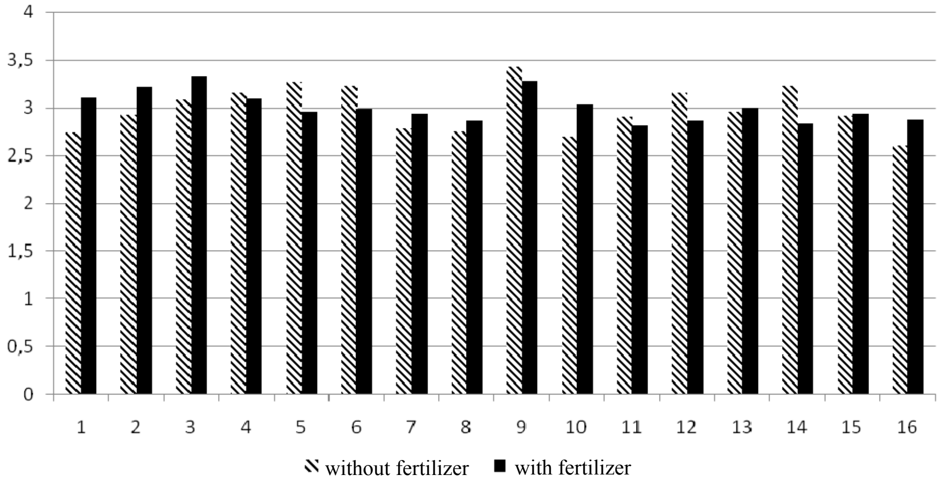
Variant number	$\bar{x}$	$\pm m$	$\pm\sigma$	V, %	P, %	t_{ϕ} (when $t_{05} = 1{,}96$)
1	2,74	0,07	0,41	14,9	2,7	6,83
2	2,93	0,08	0,56	19,3	2,7	4,81
3	3,08	0,09	0,57	18,5	2,9	3,10
4	3,16	0,06	0,44	13,8	2,0	2,94
5	3,27	0,07	0,52	16,0	2,2	1,56
6	3,23	0,06	0,37	11,6	1,8	2,20
7	2,78	0,09	0,53	19,2	3,1	5,87
8	2,75	0,06	0,39	14,1	2,2	7,37
9	3,43	0,07	0,53	15,4	2,0	–
10	2,70	0,05	0,33	12,2	1,8	8,51
11	2,90	0,06	0,46	15,9	2,2	5,65
12	3,16	0,07	0,49	15,5	2,2	2,77
13	2,96	0,10	0,54	18,2	3,4	3,76
14	3,23	0,07	0,50	15,3	2,1	2,00
15	2,91	0,06	0,42	14,3	2,1	5,68
16	2,60	0,09	0,49	18,9	3,6	7,09
Average	3,02	0,02	0,53	17,4	0,7	4,38

Figure 3
The height of Siberian cedar pine seedlings grown using fertilizer, cm

Variant number	$\bar{x}$	$\pm m$	$\pm\sigma$	V, %	P, %	t_{ϕ} (when $t_{05} = 1{,}96$)
1	3,11	0,05	0,39	12,6	1,7	2,33
2	3,22	0,08	0,50	15,5	2,4	0,99
3	3,33	0,08	0,49	14,8	2,3	–
4	3,10	0,04	0,30	9,6	1,3	2,65
5	2,96	0,05	0,38	12,8	1,8	3,96
6	2,99	0,05	0,39	13,1	1,8	3,59
7	2,94	0,05	0,37	12,7	1,8	4,15
8	2,87	0,08	0,51	17,8	2,7	4,14
9	3,28	0,06	0,38	11,7	1,7	0,51
10	3,03	0,05	0,39	12,9	1,8	3,21
11	2,81	0,06	0,40	14,3	2,1	5,38
12	2,87	0,06	0,39	13,6	2,1	4,71
13	3,00	0,06	0,46	15,3	2,1	3,32

End of the Figure 13

Variant number	$\bar{x}$	$\pm m$	$\pm\sigma$	V, %	P, %	$t_ф$ (when t_{05} = 1,96)
14	2,83	0,08	0,49	17,3	2,7	4,61
15	2,94	0,05	0,34	11,4	1,8	4,11
16	2,88	0,06	0,42	14,6	2,0	4,59
Average	3,01	0,02	0,44	14,5	0,5	3,27



The height of Siberian cedar pine seedlings with closed root system grown on substrates of different composition in two versions: without fertilizers and with fertilization

CONCLUSION

The conducted research on the growth of Siberian pine seedlings, grown with a closed root system in trays with various substrate compositions, allowed for the following conclusions:

– A complete replacement for peat-based substrates can be achieved using coconut substrate, mixed with vermiculite in a 50/50 proportion.

– When cultivating Siberian pine seedlings with a closed root system using peat mixtures produced by LLC “VELTORF” or pure peat from LLC “KrasKIP,” it is advisable to apply AgroMaster 18.18.18+3 fertilizer.

– When growing planting material with a closed root system on peat mixtures, it is reasonable to consider locally sourced peat to reduce production costs.

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ВЛИЯНИЕ ПАРАМЕТРОВ РАБОЧЕГО ОРГАНА ДИСКОВОГО РЫХЛИТЕЛЯ НА ТЕХНОЛОГИЧЕСКИЙ ПРОЦЕСС НАРЕЗКИ БОРОЗД ПРИ ЛЕСОВОССТАНОВЛЕНИИ

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Современная ситуация в области устойчивого лесопользования в России характеризуется проблемой восстановления, охраны и защиты лесов. Несмотря на значительные объёмы работ по сохранению подроста в процессе рубок главного пользования, проведению мероприятий содействия лесовосстановлению, существует устойчивая тенденция отставания темпов восстановления лесных насаждений на фоне значительного увеличения площадей вырубок и гарей. Современные технологии лесных культур могут стать эффективным драйвером роста продуктивности лесов России. Для реализации таких технологий требуется оперативная и качественная подготовка почвы в интересах последующего лесовосстановления.

Исследование направлено на решение задачи лесовосстановления в условиях вырубок. Проведен анализ конструкции дисковых рыхлителей, предназначенных для подготовки почвы в процессе работ по лесовосстановлению. Проанализированы факторы, оказывающие существенное влияние на эффективность работы плугов-рыхлителей с дисковым рабочим органом. В ходе работы определялись закономерности, влияющие на кинематические соотношения при обработке лесных почв дисковыми рыхлителями. Был установлен принципиальный характер движения пласта по поверхности рабочего органа дискового рыхлителя. На основании анализа процесса образования борозд при обработке почвы дисковым рыхлителем, даны рекомендации по выбору линейных и угловых параметров рабочего органа. На основе анализа сформулированы требования к дисковым плугам-рыхлителям, которые смогут эффективно осуществлять основную подготовку почвы в условиях вырубок, в разнообразных почвенно-климатических условиях России. Материалы исследований, рекомендованные линейные и угловые параметры рабочих органов могут быть использованы при проектировании и усовершенствовании лесных рыхлителей с дисковыми рабочими органами.

Ключевые слова: *лесовосстановление, дисковые рыхлители, плуги, анализ, рабочий орган, кинематика пласта.*

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INFLUENCE OF THE PARAMETERS OF THE WORKING BODY OF THE DISC RIPPER ON THE TECHNOLOGICAL PROCESS OF CUTTING FUROWS DURING REFORESTATION

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The current situation in the field of sustainable forest management in Russia is characterized by the problem of restoration, conservation and protection of forests. Despite the significant amount of work to preserve the undergrowth in the process of felling the main use, carrying out activities to promote reforestation, there is a steady trend of lagging behind the rate of restoration of forest plantations against the background of a significant increase in the areas of felling and burnt areas. Modern technologies of forest crops can become an effective driver of growth in the productivity of Russian forests. The implementation of such technologies requires prompt and high-quality soil preparation in the interests of subsequent reforestation. The study is aimed at solving the problem of reforestation in the conditions of clearings. The analysis of the design of disc rippers designed for soil preparation in the process of reforestation was carried out. The factors that have a significant impact on the efficiency of the plow-rippers with a disk working body are analyzed. In the course of the work, regularities were determined that affect the kinematic relationships during the processing of forest soils with disc rippers. The fundamental nature of the formation movement on the surface of the working body of the disk ripper was established. Based on the analysis of the process of furrow formation during soil cultivation with a disk cultivator, recommendations are given on the choice of linear and angular parameters of the working body. Based on the analysis, the requirements for disc cultivator plows are formulated, which will be able to effectively carry out basic soil preparation in clearing conditions, in a variety of soil and climatic *conditions in Russia. Research materials, recommended linear and angular parameters of the working bodies can be used in the design and improvement of forest rippers with disk working bodies.*

Keywords: *reforestation, disc rippers, plows, analysis, working body, formation kinematics.*

INTRODUCTION

The forests of Russia occupy one fifth of the world's forest area and being one of the renewable natural resources, satisfy numerous needs of the economy and society in forest resources, fulfill the most important environment-forming, environment-protecting and other useful functions. However, at present the problems of forest conservation and utilization are complex and diverse.

The Strategy for the Development of the Forest Complex of the Russian Federation until 2030 considers insufficient reforestation efficiency as one of the main problems constraining the development of the forest complex. Having almost halved over the last 20 years, the annual volume of reforestation has stabilized at the level of 800–900 thousand hectares. Due to non-compliance with agrotechniques of cultivation of established forest crops, their high mortality is observed in the period before their conversion to the forested area. The need of established forest crops in agro-technical maintenance is met only by half. At the same time, the land holders of forest areas are not sufficiently interested in forest reproduction, effective use of harvesting areas and development of forest infrastructure.

In the Russian Federation, the process of coniferous species replacement by deciduous species is unfavorable for the forest industry due to low availability of fellings for the purpose of forest plantation maintenance. At the same time, the share of artificial reforestation in the total volume of reforestation remains low (22 % on average) compared to foreign countries. The predominant method of reforestation is the promotion of natural regeneration. Artificially created forest plantations require agrotechnical maintenance. At the same time, the need for agrotechnical care is met only by 60%. Due to non-compliance with agrotechnics of cultivation of established forest crops, their death is observed in the period before their conversion to the forested area [1].

The majority of forests grow on heavily sodded soils, where reforestation activities are not successful without effective preparation. Insufficient tillage is one of the major problems, partly due to lack of suitable equipment and partly due to lack of funding. The wide range of different types of equipment developed in Russia for soil cultivation (including the creation of micro-tillage) does not seem to be fully utilized.

In Russia, there are quite a lot of studies devoted to the issues of soil cultivation (Pisarenko and Merzlenko, 1990, Kalinichenko et al., 1991, Volkov, 1998, Melekhov, 2002, Sokolov, 2006) [2–6]. Research on increasing the passability and durability of tillage implements used in the conditions of reforestation on undisturbed areas is becoming particularly important. Such implements include rippers with disc working bodies, which are designed with both passive and active working ones. The use of disc rippers in reforestation without stump removal is relevant to meet environmental requirements as well as cost-effective [7]. Experiments conducted by Brakke Forest show that there is a big difference in results depending on where and how the seedlings are planted. Experiments show that the depth and location of planting, the type of soil are crucial for the survival and development of the seedling. The Bracke range of milling rippers (Fig. 1) is recognised as very effective [8].

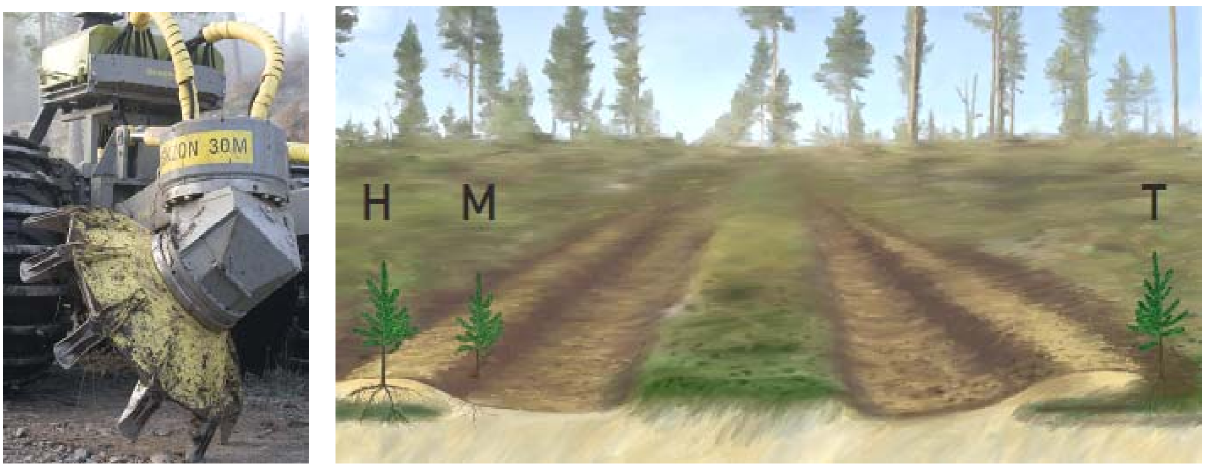

Fig. 1: Bracke T26 working body and the result of shaping of planting spots:
T – inverted turf; H – mineral soil mounds on inverted turf; M – mineral ground mounds on mineral soil

Tools with disc working bodies reduce the time of soil preparation, make it possible to work on unprepared sites with local irregularities [9; 10]. Bracke T21.a disc ripper is used for work on small plots. It is available in two modifications (with a three-point attachment for coupling with tractors and with a frame for installation on a forwarder). The design of this machine allows manual regulation of the disc tilt at nine different angles [11]. More powerful rippers Bracke T26.a, Bracke T45.a are used for work on difficult and cluttered areas.

The design characteristic of the Bracke T26.a ripper is the possibility to set the arms and discs at different widths and angles, which allows varying the parameters of ground pressure and the pressure of the working body. The Bracke T45.a ripper is also an effective tool on unlogged fellings, as it provides simultaneous processing of four strips [12]. During reforestation on fellings, promising designs of disc rippers are also used for basic soil preparation. These machines perform simultaneous tillage and partial clearing of cultivated strips by shifting felling pieces with their working bodies. The rippers allow to provide quality soil treatment in difficult conditions of unploughed and cluttered fellings [13].

For effective operation of forest disc rippers it is necessary to study the influence of parameters of the working surface of ripper blades on the technological process of furrow cutting. The existing forest ploughs work unsatisfactorily due to inconsistency of accepted parameters to the technological task of furrow cutting. The work of a modern disc ripper requires justification of parameters of the working body - the knife-blade of the ripper to ensure a turning over of the soil layer so that the mineralised part is on top and the turf part is at the bottom of the mineralised soil roll (Fig. 1). In this case a certain analogy with the work of mouldboard classical ploughs in the aspect of the movement of the soil layer on the forming elements of the mouldboard can be traced. On the basis of the above stated, let us formulate the aim and objectives of the research.

PURPOSE AND OBJECTIVES OF THE RESEARCH

The purpose of the research is the influence of parameters of the working body of the disc rippers on the technological process of cutting furrows during reforestation.

The stated purpose allows to assign the research objectives:

1. To determine the factors influencing the kinematics and deformation of the layer.

2. To determine the characteristics of the layer movement on the working surface of the working body of the disc ripper.

RESULTS AND THEIR DISCUSSION

Figure 2 shows the working body of the disc ripper - cutter. The cutter consists of removable blades 1 and base body 2.

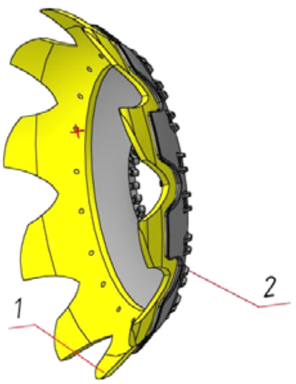

Fig. 2. Cutting working body

The shape and parameters of the furrow (layer) cross-section, the angle ε of the knife-blade inclination to the furrow bottom, the angle γ0 of the cutting blade inclination to the furrow wall, the shape and parameters of the formers, the parameters of the guide, the shape and parameters of the field cut curve, the pitch of the helical surface are among the parameters that have a significant influence on the kinematics and deformation of the layer. Nowadays, when designing forest ploughs, the shape of furrow cross-section is accepted in the form of rectangle or trapezoid. Let us consider the features of rectangular and trapezoidal forms of furrow cross-section.

The purpose of furrow cutting is to prepare the soil for sowing or planting forest crops in a furrow or layer. It follows that the furrow and layer widths, i.e. the mineralised strip, should be as wide as possible. From this point of view, the trapezoidal cross-sectional shape has a number of advantages compared to the rectangular cross-sectional shape (Fig. 3).

With a given furrow width, the cross-sectional area of the trapezoid is smaller. By reducing the furrow cross-section, the work required to turn the layer is also reduced. It is important to determine the required traction forces, because their value determines the required power of the traction device used to drive the disc ripper [14].

The trapezoidal cross-section reduces the force required to cut the layer. Studies [15–18] have shown that the characteristics of the cutting process are significantly influenced by the standing of the ground and the traction resistance of the plough depends on the length and location of the cutting blade. Side (vertical) blades require more force, so they should be excluded from the cutting process if possible. For the same working width, the traction resistance increases with increasing blade length.

When the vertically placed cutting blade is deflected in the direction perpendicular to the movement, the cutting force and specific resistance decrease. Thus, deflecting the knife at an angle of 45º at a cutting depth of 0.28m. causes a 25 % reduction in specific resistance compared to the resistance of the knife placed vertically.

The trapezoidal shape of the furrow cross-section eliminates vertical cutting of the layer and also reduces the so-called active blade length. Assuming that the active blade length is the length of the blade cutting the layer along the bottom of the furrow. The active blade length can be characterised by the coefficient of blade length reduction, which is equal to:

$$L_r = \frac{L_T}{L_P} = \frac{(b-\Delta)\sin\gamma}{b\sin\gamma} = \frac{b-\Delta b}{b}, \tag{1}$$

where L_r – blade length at rectangular cross-section; L_t – blade length at trapezoidal cross-section; Δb – undercutting of the layer along the bottom of the furrow.

For trapezoidal shape of the furrow cross-section the value of Δb is defined as:

$$\Delta b = \frac{t}{\operatorname{tg}\lambda}, \tag{2}$$

where t – height of the cutting blade; λ – angle of inclination of the cutting blade.

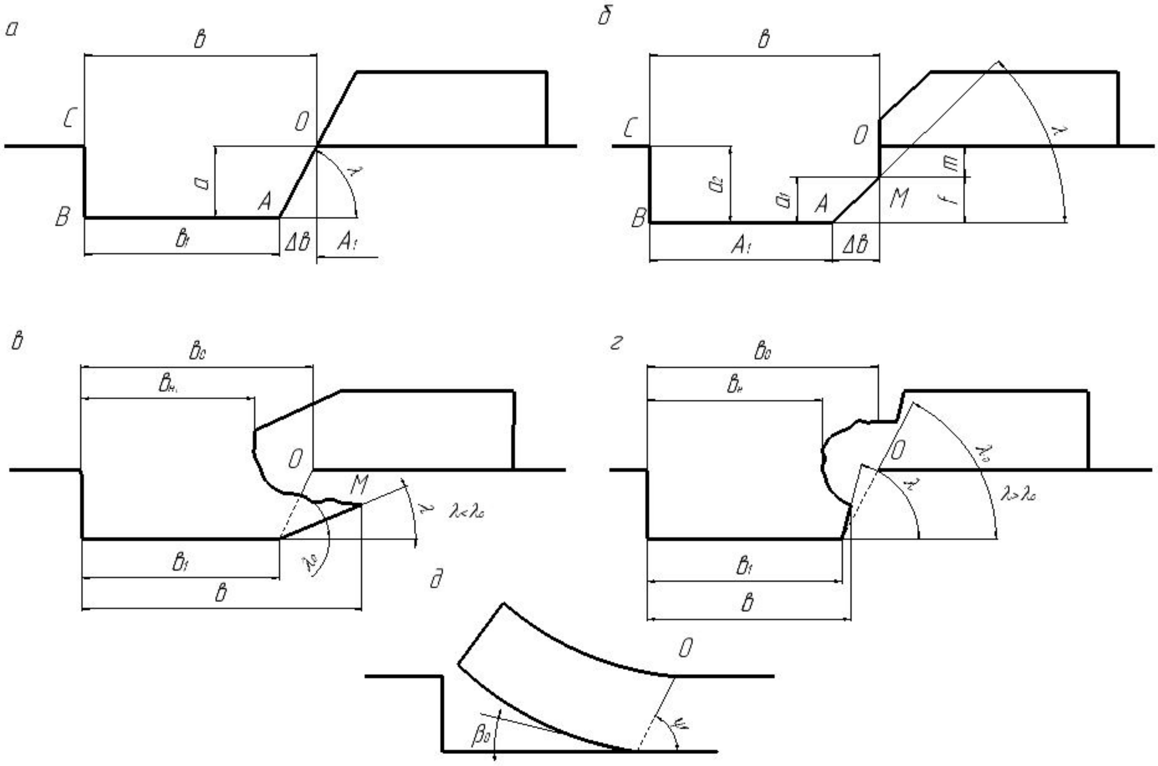

Fig. 3.Scheme of formation of the soil layer

The shape of the furrow cross-section should be chosen so that K_L, is less than 1. Thus, in order to ensure a certain furrow width, in case of rectangular cross-section of the layer it is necessary to cut the soil up to point A_1 (Fig. 3, *a*), and in case of trapezoidal cross-section up to point A. Consequently, in the second case the active length of the blade is considerably reduced. All this should lead to a reduction of traction resistance. In case of trapezoidal cross-section of the body the soil shattering at the furrow edge is reduced. For a rectangular furrow cross-section, the lateral edges will crumble over time. It means that there is no need to do an excavation of a part of soil, which is still crumbling. Insufficient substantiation of the rational parameters of the working body of the disc ripper -cutter, leads to the fact that manufacturers produce disc rippers with blades of chosen ‘intuitively’ shape (Fig. 4).

Studies [19; 20] have shown that the type and shape of disc ripper has a significant effect on traction resistance. For example, with tractors of traction class 14 kN it is possible to use successfully not only single disc active ripper, but also passive double disc version under soft soil conditions. In more difficult conditions with tractors of 30 kN traction class, it is recommended to use the active double disc version of the ripper to ensure high quality indicators.

The analysis of industrial samples of disc rippers allows to draw a conclusion about the maximum spread of trapezoidal shape of blades. Most often the knife-blade (Fig. 5) contains a cutting blade part transitioning smoothly to the ploughshare part, forming the surface of the mouldboard and transporting the soil layer.

Taking the shape of the cross-section as a rectangular trapezoid, let us find out at what angle λ should be placed the side. Based on experiments [21], it was found that to ensure minimum energy consumption with the plough working surface, it is recommended to place the blade at an angle of 60–75°.

Graphical and analytical studies of different mouldboards have allowed us to establish the nature of layer movement on the working surface of the plough body. Depending on the law of surface formation, the layer either shifts to the side (if the cross sections on the vertical projection of the mouldboard do not intersect in one point) or turns around some axis (through which the cross sections pass or around which they turn). So, under the influence of the working surface the layer is forced to turn around some axis. In order to facilitate the layer rotation, the undercutting knife should be positioned so that its end coincides with the point *O*, which is the axis of layer rotation (Fig. 3, *a*). In this case, the furrow width will correspond to the designed surface.

If the undercutting knife is positioned at an angle $\lambda<\lambda_0$ (Fig. 3, *c*), where λ_0 is the angle of inclination of the knife at which its plane passes through the layer rotation axis, it actually does not fulfill its role. After all, the surface is designed so that the layer turns around the axis *O*, and near this axis the layer is not cut. Under the influence of the working surface, the layer is forcibly rotated around the *O* axis, bending and breaking the uncut part of the layer. If the undercutting knife is placed at an angle $\lambda>\lambda_0$ (Fig. 3, *d*), the layer width will also decrease, which generally corresponds to the data obtained [22].

In both the first and second cases, the furrow width will decrease due to the ‘overthrust’ of the layer. By the term ‘overthrusting’ we mean the placement of a part of the layer above the furrow. This phenomenon will occur due to the following factors:

1. The height of the undercutting part of the cutter blade is insufficient for complete undercutting of the layer (the end of the undercutting blade does not coincide with the *O* axis of the layer rotation).

2. The helical surface guide is deflected to the left in the direction of movement from the longitudinal plane.

Let us consider the substantiation for choosing the angle λ of inclination of the blade undercutting part (Fig. 3). It is obvious that the angle λ for a specific working surface with a given furrow width *b* cannot be chosen arbitrarily, even for the condition when the knife edge coincides with the axis *O*. If the angle λ is small, the blade of the knife will be too short. At λ= 90°, the furrow section approaches a rectangle, which, as mentioned above, is also unpractical. Consequently, the angle λ must be chosen for some other considerations. The following factors can be taken as the main ones:

1. *Angle ψ of soil destruction during wedge penetration.* The technological effect of the wedge, i.e. the deformation of the layer produced by it, does not depend on the direction of movement and remains unchanged both when the wedge moves perpendicular to the blade and when it moves at an angle $_{\gamma 0}$ < 90°.Then, applied to the plough body of the knife-blade of the soil tiller, a straight curved wedge with a cutting angle $_{\beta 0}$ (Fig. 3, *e*) can be conditionally considered in the cross-section passing through the end of the ploughshare. When such a wedge is moving, the soil breaks under angle ψ ≅ 45°÷50°. So, to facilitate the process of layer undercutting, the angle λ of the cutting blade inclination should be close to angle ψ, i.e. λ ≅ ψ ≅ 45°÷50°.

2. *Optimum combination of blade and share part of the soil tiller blade.*

In order for the blade part to be durable, its length must be kept to a minimum. A minimum length is possible at λ = 90°, but then the shape of the furrow cross-section is irrational. The length of the knife part increases when λ is considerably more than 45°. So, for reasons of durability, it is also most rational to adopt λ= 45°.

Natural slope angle. To prevent the furrow walls from crumbling, the angle λ of inclination of the cutter and its blades should not exceed the natural slope angle. The natural slope angle for different soils ranges from 35° to 50°.

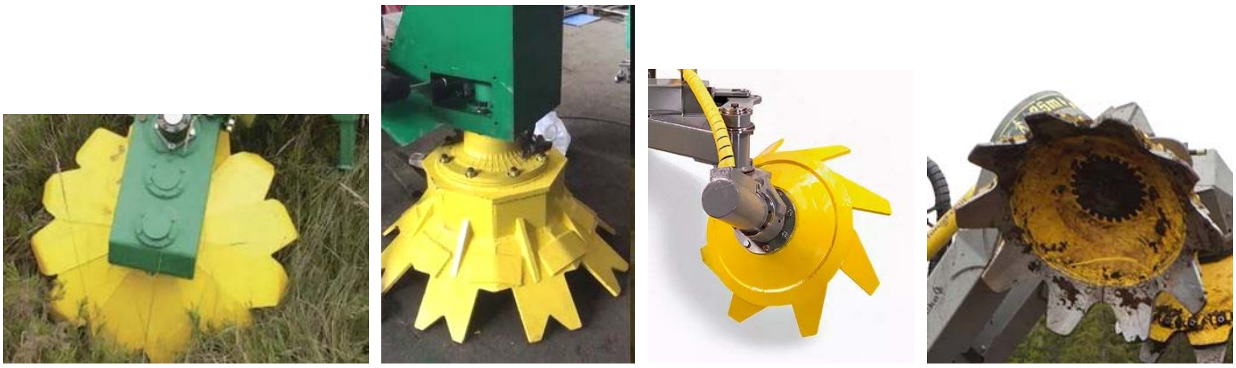

Fig. 4. Varieties of working knife-blades mass-produced by the industry:
From left to right in the form of petals (TPF-1N Anschi); rectangular (TT26 from TD Forwarder Ltd); asymmetrical trapezium (Bracke t21.b); symmetrical trapezoid (Bracke Forest t26.b)

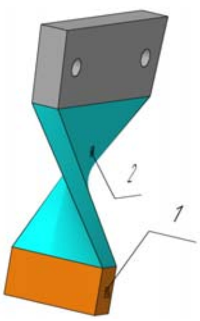

Fig. 5.Cutting blade of the soil tiller:
1 – knife part; 2 – blade part

It should be noted that due to the need to make furrows of different depths, the shape of the furrow cross-section in the form of a regular trapezoid is not always realised. If the height of the undercutting knife is chosen so that when working at a depth of a_1, the point *M* of the knife coincides with the field surface and passes through the layer rotation axis *O*, then the cross-section of the furrow formation is trapezoidal (Fig. 3, *b*). If the treatment goes to a depth $a_2 > a_1$, the point *M* will not coincide with the field surface. In this case, the furrow cross-section is obtained in the form of *OMABC*. Since the real depth of the furrow will be constantly changing and will depend on many factors (presence of stumps, local soil irregularities), the end of the blade not only does not coincide with the rotation axis of the layer *O*, but the blade plane also does not pass through the axis *O*. Consequently, the knife part of the blade cuts only a part of the layer height. Due to the fact that some layer height remains uncut, a layer overthrust is formed, which reduces the calculated furrow width. This disadvantage can be avoided by correct selection of the position of the layer rotation axis *O* at the given layer width *b*, furrow bottom width b_1, angle λ, as well as the largest and the smallest calculated furrow depths a_{max} and $a_{min.}$.

Fig. 6 shows the shape of the furrow cross-section. The distance from the left edge of the furrow to the axis *O* of the layer turnover, in accordance with Fig. 6 a, will be taken from the expression:

$$b_0 = b + (3 - 6)\ \text{см}, \tag{4}$$

where b is the calculated furrow width.

Fig. 6, *b* shows the furrow cross-section taking into account the layer overthrust. A value of 3-6 cm will avoid reducing the calculated furrow width due to overthrust, which will be observed due to the need to work at different depths.

Thus, based on the analysis performed, the inclination angle λ should be taken as 45°÷50°. At the same time, the vertical height of the blade part should not exceed $t = \Delta b \le a_{\min}$. When designing the working surface, the layer turnover axis should be shifted from the end of the ploughshare blade by 3-6 cm.

Let us consider the question of setting the angle ε of the blade direction of the disc soil ripper to the bottom of the furrow. Some researchers [18–21] recommended the value of the angle within 20…30°. However, the conducted researches were mainly concerned with the study of its influence on the traction resistance. The question of necessity to change the angle ε from the position of layer turnover kinematics is of great importance. Let's consider the influence of the angle ε on the layer kinematics. We assume the condition of a flat wedge (Fig. 7).

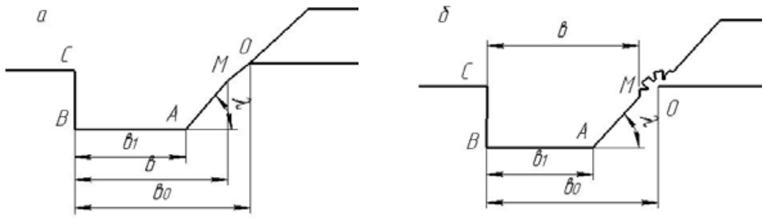

Fig. 6.Shape of the furrow cross-section

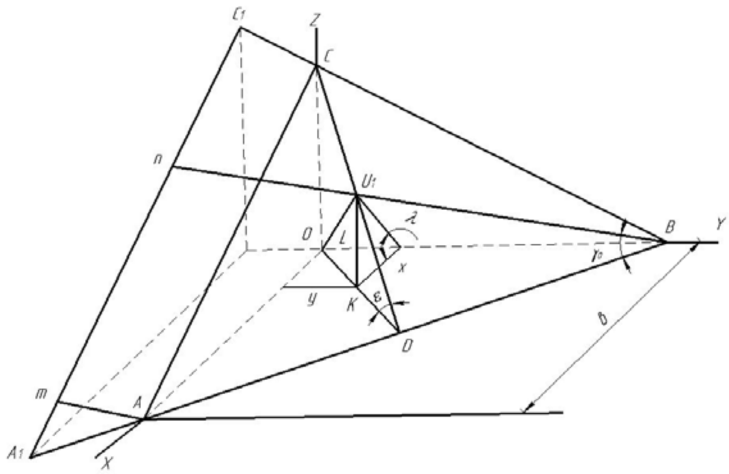

Fig. 7.Scheme of layer movement along the oblique wedge

The Y-axis is in the direction of motion, the X-axis is across the motion, and the Z-axis is vertically upwards. Let the point *B* of the wedge in the first period of motion coincides with the coordinate origin *O* and, moving with constant velocity υ, passes the path $OB = \upsilon t$. During this time, the point *O*, belonging to the layer, will move to the point O_1. Under the condition of moving of the layer without its compression, without taking into account friction, then $OB = O_1B$, $OD = O_1D$. Consequently, the point O_1 lies in the plane *COD*, perpendicular to the blade of the wedge *AB*. In this case, the relative trajectory of the point O_1 to the blade is deflected by an angle γ_0. The equations of motion of the point O_1 of the layer can be written in the form:

$$x = OB \sin\gamma_0 \cos\gamma_0 (1 - \cos\varepsilon), \tag{5}$$

$$y = OB \sin^2\gamma_0 (1 - \cos\varepsilon), \tag{6}$$

$$z = OB \sin\gamma_0 \sin\varepsilon. \tag{7}$$

Excluding constants from the equations of motion, we obtain the trajectory of motion of point O_1 of the layer:

$$\frac{x}{\cos\gamma_0 (1 - \cos\varepsilon)} = \frac{y}{\sin\gamma_0 (1 - \cos\varepsilon)} = \frac{z}{\sin\varepsilon}. \tag{8}$$

When studying layer kinematics, it is necessary to limit the movement of the layer in any direction of the coordinate axes. For the disc ripper operation it is necessary to reduce the lateral displacement. Let's consider the obtained equations for selection of parameters, providing minimum displacement of the layer. Let us preliminarily determine the kinematics of point *A* of the layer, which is located from point *B* at a distance *b* (width of the layer) along the *X* axis. Since the blade is located at an angle γ_0 to the furrow wall, the point *A* of the layer will touch the blade of the wedge when it passes the distance:

$$OB = \upsilon t = \frac{b}{\operatorname{tg} \gamma_0}. \qquad (9)$$

Before point A meets the blade of the wedge, the motion of the layer is determined by geometrical relations without taking into account the acting forces. At further movement, when the layer, rising along the wedge, loses its connection with the surface, gravity starts to exert a greater influence, and the layer will tend to move to the side and the trajectory to bend. This is true for an unbound layer (e.g., in the cultivation of unbound soils). In the case of a bound layer, typical of forestry operations, gravity can be neglected because the turf in the layer will act as a reinforcement to prevent the layer from bending. Consequently, point B of the layer in its relative motion will continue to move along the line B_n, and point A will move along the line Am. So, considering the movement of a bound layer, we can consider that the movement of point A is subject to the same laws as point B. Consequently, the equations obtained are also valid for point A.

Let us find out the character of change for the lateral displacement parameter (abscissa x) depending on the change of the angle ε. It is also important to establish the dependence $z = f(\varepsilon)$, which characterises the layer uplift, and $\operatorname{tg}\lambda = f(\varepsilon)$ which characterises the tangent of the trajectory inclination angle in the plane of lateral displacement (transverse-vertical plane). Figure 8 shows graphs illustrating the effect of change parameters of oblique plane wedge on layer kinematics.

The graph (Figure 8, *a*) of the dependence $x = f(\varepsilon)$ is obtained by substituting different values of angles *e* into equation (5). The graph illustrates that as ε increases from 0 to 90°, the value of x increases, reaching the highest value at ε = 90°. From the graph $z = f(\varepsilon)$ (Fig. 8, *b*) it follows that with the increase of ε the height of layer elevation increases. To draw the graph $\operatorname{tg}\lambda = f(\varepsilon)$ we will take the ratio:

$$\operatorname{tg}\lambda = \frac{z}{x} = \frac{\operatorname{ctg}\frac{\varepsilon}{2}}{\cos\gamma_0}. \qquad (10)$$

The graph $\operatorname{tg}\lambda = f(\varepsilon)$ shows (Fig. 8, *c*) that the largest value of tgλ corresponding to the minimum lateral displacement of the layer occurs at $\varepsilon \to 0$.

Thus, the influence of the angle ε on the layer kinematics has been established. The layer under the influence of a flat triangular wedge is displaced laterally. To reduce the lateral displacement of the layer it is necessary to strive to reduce the angle ε. For point B of the layer, lateral displacement is acceptable, as it is accompanied by uplift and in general does not significantly affect the kinematics of the layer. Therefore, the angle ε_H, can be chosen based on the minimum traction resistance. For point A, lateral displacement and uplift of the layer are very undesirable, because in this case the kinematics of the layer differs significantly from the theoretical one. Since the layer at point A is connected with the soil mass, its lifting, carried out without turnover, causes crushing of a part of the layer and, as a consequence, increased pressure on the mouldboard. The angle ε should be variable along the length of the blade's ploughshare part, decreasing from the blade part to its points of attachment of the blade to the disc of the soil tiller. For constructive reasons the angle ε_K should be chosen within the limits ε_K = 10÷15°. The angle ε_H should be chosen based on the least traction resistance within the limits ε_H = 25÷30°. Reducing the angle ε_K prevents sliding and ensures retention of the layer on the mouldboard surface.

CONCLUSION

The Russian Federation possesses significant forest resources. Modern reforestation technologies are based on the use of advanced high-performance equipment. Such equipment includes disc rippers, which use both passive and active working elements. The efficiency of such equipment is influenced by a number of factors. In the process of research were established certain regularities affecting the kinematic relations in the process of forest soil cultivation with disc rippers. The character of movement of a layer on a surface of a working body of a disc ripper has been defined. On the basis of the analysis of process of formation of furrows at soil cultivation by a disc ripper, the following parameters of a working body are recommended: trapezoidal cross-section of a furrow with angles of inclination of forming 45°; the angle of inclination of a ploughshare part of a working knife-blade of a disc ripper should decrease from a toe of a blade to its back surface (cropping to a disc).

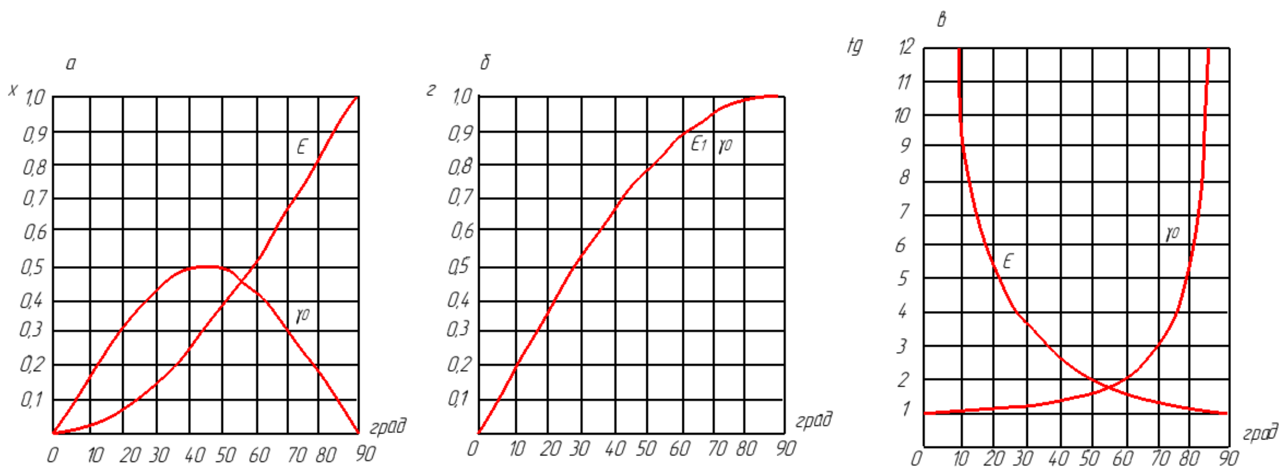

Fig. 8. Graphs illustrating the influence of change parameters of oblique flat wedge on layer kinematics

The angle ε_K should be 10÷15°, ε_H is accepted in the range of 25÷30°. Reducing the angle ε_K prevents sliding and provides layer retention on the mouldboard surface.

Materials of researches can be used at designing and improvement of forest rippers with disc working bodies.

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ВЛИЯНИЕ РАЗМОЛА ОДНОЛЕТНИХ РАСТИТЕЛЬНЫХ ПОЛИМЕРОВ НА ПРОЦЕСС ПОЛУЧЕНИЯ МЕЛКОДИСПЕРСНОЙ ЦЕЛЛЮЛОЗЫ

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Целлюлозно-бумажная промышленность является одной из базовых отраслей экономики, она играет важную роль в повышении научно-технического уровня практически всех отраслей хозяйства. Основным источником сырья данной промышленности является древесина хвойных пород. Огромная база природных ресурсов привлекает инвестиции в эту отрасль, стимулирует рост производства. В России в основном используется экстенсивная модель лесопользования, т.е. ведется вырубка природного леса. Трудность восстановления лесных ресурсов естественным способом состоит в том, что данный процесс занимает много времени и имеет различные факторы, от которых зависит скорость восстановления лесных экосистем.

В работе рассмотрен способ получения мелкодисперсной целлюлозы из альтернативного древесине источника сырья и факторы, оказывающие влияние на разработку волокнистой суспензии, в дисковой мельнице. Проанализирована величина степени полимеризации целлюлозы предварительно прошедшей стадию размола, при разной степени помола по шкале Шоппер–Риглера.

Ключевые слова: *хвойные породы, однолетние растения, размол волокнистых материалов, мелкодисперсная целлюлоза, степень полимеризации.*

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THE EFFECT OF GRINDING ANNUAL PLANT POLYMERS ON THE PROCESS OF OBTAINING FINE CELLULOSE

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The pulp and paper industry is one of the basic branches of the economy, it plays an important role in improving the scientific and technical level of almost all sectors of the economy. The main source of raw materials for this industry is coniferous wood.The huge base of natural resources attracts investments in this industry, stimulates the growth of production. In Russia, an extensive model of forest management is mainly used, i.e. natural forest is being cut down. The difficulty of restoring forest resources in a natural way is that this process takes a lot of time and there are various factors on which the speed of restoration of forest ecosystems depends.

The paper considers a method for obtaining fine-dispersed cellulose from an alternative source of raw materials to wood and factors influencing the development of a fibrous suspension in a disc mill. The value of the degree of polymerization of cellulose that has previously passed the grinding stage, with different degrees of grinding on the Shopper–Rigler scale, is analyzed.

Keywords: *coniferous species of bio-damaged wood, grinding of fibrous materials, microcrystalline cellulose, degree of polymerization.*

INTRODUCTION

The destruction of forests as a result of industrial logging and forest fires has a negative impact not only on the gas composition of our atmosphere, increasing the risk of the greenhouse effect on the earth, which results in a disturbance of the ecological balance of all ecosystems [1]. Over the last two centuries, the concentration of CO_2 in the atmosphere has increased by 20% [2]. It is suggested that due to the increase in the intensity of logging, in addition to anthropogenic fires, there is a strengthening effect of factors influencing the increase in CO_2 concentration. According to the Centre for Forest Ecology and Productivity of the Russian Academy of Sciences, of the 500 billion tonnes of carbon contained in all terrestrial biomass, Russian forests contribute 34 billion tonnes, of which more than 25 billion tonnes are coniferous forests [3]. The increasing growth of logging of forest resources and their preparation for industrial use is associated with the fact that fibrous cellulose-containing semi-finished products are a valuable source of raw materials for producing:

– timber – products obtained by mechanical processing, mainly from the trunk of a tree (roundwood, sawn timber);

– raw materials for forestry production, obtained from trunk, roots, crowns (larch, oak, chestnut bark, pine stump wood);

– composite materials – sheet, board or other materials obtained with the help of binders (plywood, chipboard, laminates, blockboards, etc.);

– modified wood – solid wood with directionally modified properties (pressed wood, plasticised with ammonia, modified with synthetic resins, etc.);

– cellulose, paper and wood-fibre materials (wood pulp, paper, cardboard, wood-fiber boards, etc.);

– products of hydrolysis and yeast production (alcohol, fodder and food yeast, furfural, etc.);

– products of wood-chemical production (turpentine, rosin, tannin extracts, biologically active substances, etc.).

According to experts' estimates, 42 % of all wood harvested in the world is used for the production of paper products, and gas emissions from paper production is three times higher than the emissions from all existing air transport [4; 5].

This is due to the fact that fibrous cellulose-containing semi-finished products are used not only in pulp and paper products, but also in the form of other products of their deep processing, in particular, powdered cellulose materials. Moreover, the popularity of pulp and paper products in various industries is only increasing. About 200 thousand tonnes of various kinds of powdered cellulosic materials are produced in the world [6]. Modified microcrystalline cellulose due to its unique properties, allows to obtain materials with improved properties. It is used in the form of powder in such industries as medical and pharmaceutical (as an auxiliary agent in the manufacture of tablets); food (in the manufacture of baked products, sweets, canned fish, mayonnaise, meat and dairy products); in cosmetics as the basis of powders, creams; oil and gas industry in the production of plastics, polymer films, for the production of building materials, as a starting material for the production of nanocrystalline cellulose; in the composition of packaging paper and cardboard to increase their strength [6].

In the regard of the stated above, the problem of rational use of wood is acute. In our opinion, it is possible to solve partially the problem of resource saving by production of microcrystalline cellulose from an alternative source to wood, a rapidly renewable raw material of annual herbaceous plant (industrial hemp). The undeniable advantages of cultivating hemp is the possibility of obtaining a large accumulation of wood (shive) in the stem in a much shorter (4 months) period of time than wood (50 years). A hectare of hemp produces about 6 tonnes of cellulose per year, which is several times more than the annual growth of a hectare of forest. Moreover, hemp is a very unpretentious crop to climatic conditions and grows successfully in a large latitudinal range. In addition, the content of cellulose extracted from hemp is at least 5–7 times higher than from wood [7; 8]. By using hemp cellulose, some countries have significantly reduced deforestation and protected the ecological environment [9-14]. The varied use of hemp products and the ability to obtain good yields without pesticides confirm the advantages of hemp over other crops [15]. The hemp stalk consists of two parts:

– hemp (long fibers of hemp stalks) is a valuable industrial raw material, used in the production of various types of ropes, cables, twines, cords, steel rope cores, technical fabrics and clothing;

– shive (the woody parts of the stalks that remain after the stalks have been processed, the short fibers) accounts for 65–70 % of the weight of the processed hemp stalks. The unspun part of the hemp stem (shive), which is formed after extraction of fiber (hemp) from it, is considered to be a by-product of hemp production and can serve as a raw material for the paper and chemical industries, for the manufacture of building materials, as well as being used as fuel and as a substrate for growing mushrooms [7]. Compared to hemp, shive has a shorter length of fiber and higher lignin content, which prevents its use in the production of high quality papers. Whereas length of fiber does not have much influence in the production of powdered cellulosic materials, and the lignin content of cellulosic fiber can be reduced by milling the fibrous suspension in milling equipment. At the same time, one of the main problems in obtaining powdered cellulosic materials by chemical method is the disposal of the used acid solution.

The relevance of the research performed by the authors is to consider the possibility of using an alternative to wood source of raw materials for the production of microcrystalline cellulose, as well as to reduce the harmful chemical impact on the environment when obtaining the finished product from raw materials of annual plants (industrial hemp). At the same time, the analysis of literature sources has shown that there are practically no studies about obtaining microcrystalline cellulose from hemp after grinding in a disc mill.

MATERIALS AND METHODS OF RESEARCH

Researches in the field of obtaining microcrystalline cellulose with preliminary grinding of fibrous semi-finished products by blade and bladeless grinding methods are carried out in the Reshetnev Siberian State University of Science and Technology, in the laboratory of the Department of Machines and Apparatuses of Industrial Technologies [16-18].

The object of research is the process of microcrystalline cellulose production.

The subject of the study is the grinding of fibrous mass in a disc mill.

The purpose of the work is to study the effect of grinding on the process of obtaining microcrystalline cellulose.

The raw material was shive extracted from industrial hemp.

The objectives of the study included:

– grinding of the fibrous mass and analysis of the factors influencing its grinding in a disc mill [16];

– treatment of the fibrous mass by chemical method and determination of its degree of polymerisation;

– comparison of the degree of polymerisation of cellulose macromolecules at different grinding degrees according to the Shopper-Rigler scale.

The parameters characterising the type of powdered cellulosic material include: cellulose processing method, degree of polymerisation, cellulose structure, size of particles [6]. Therefore, the following laboratory methods were used to control the process of obtaining microcrystalline cellulose from shive of industrial hemp:

• measurement of the grinding degree by ^{0}ShR was carried out in accordance with ISO 5267-1 (1999) [19];

• lignin content was determined according to State Standard 11960–79 [20];

• the mass fraction of alpha-cellulose was determined according to State Standard 595–79 [21];

• determination of the degree of polymerisation was carried out in accordance with State Standard 9105–74 [22].

Cellulose extraction from shive of industrial hemp was carried out with a acid liquor, the main components of which were sodium hydroxide and sulphide (NaOH and Na_2S). Cooking was carried out in a laboratory autoclave at a temperature of 170–171 ºC for 3 hours.

The fibrous mass with a concentration of 1 % was ground in a semi-industrial disc mill from 15ºShR to 83ºShR. The rotor speed of 2000 rpm and an inter blade gap of 0.1 mm were chosen as the most effective for grinding time and the degree of fibrous processing, on the basis of earlier studies conducted at the Department [16; 23]. Fig. 1 shows the scheme of the experimental (semi-industrial) facility of blade grinding. Table 1 shows its technical characteristics.

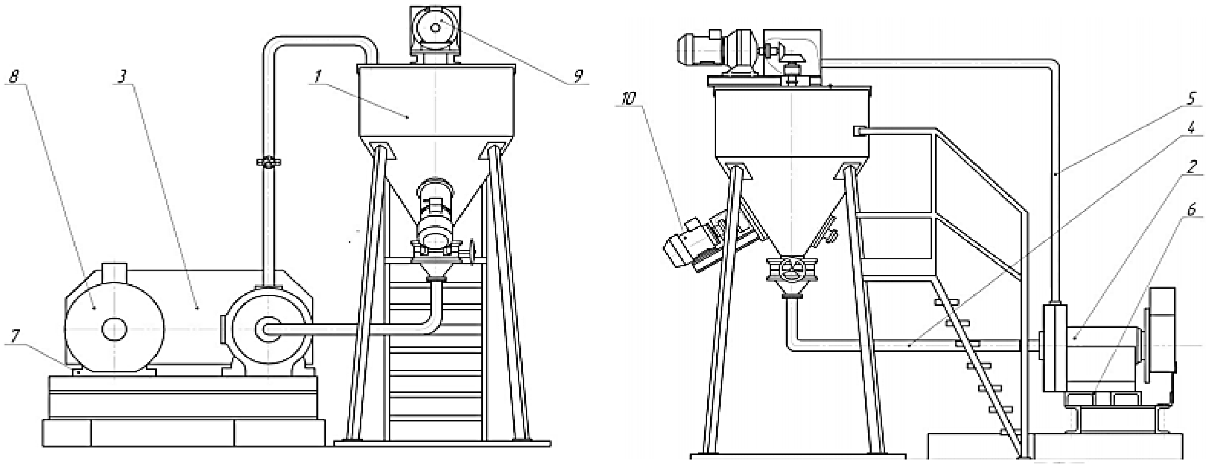
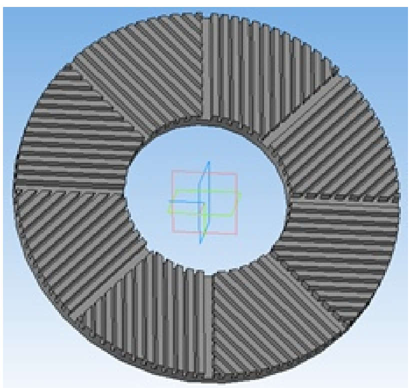


Fig. 1.Scheme of experimental blade grinding facility:
1 – hydrobrushing pulper; *2* – disc mill; *3* – belt drive; *4* – pressure pipe; *5* – circulation pipe; *6* – frame;
7 – fixing; *8*, *9*, *10* – electric motor

Table 1
Technical characteristics of the blade grinding facility

Dimensions of disc mill (length +width+height),m	0,95×0,6×0,8
inter blade gap, mm	0÷6
number of rotor shaft rotations, rpm	0÷2000
material of blade element	Steel 40XH
nominal motor power, kW	22
number of motor output shaft rotations, rpm	750



– outside and inside diameters: D = 290mm, d = 130mm;
– thickness and height of the blade: δ = 4mm; h = 4mm;
– width of the groove, *b* = 4mm;
– cutting length in second, Ls = 25213m/s;
– contact area of rotor and stator blades, F = 0,0076m^2;
– the ratio of the surface area of blades to the total surface area of the element, F_{size} / F_{total} = 22,5 %

Fig. 2. Scheme and characteristics of the blade grinding element

Changing the crossing angle of the blades of the grinding element allows to vary the ratio of hydrating and shortening effect on the fibrous material. The grinding of fibrous mass was carried out using a traditional eight-sector element with a rectilinear shape of blades with an angle of 22.5° (Fig. 2), which provides an optimal ratio of fibrillating and cutting effects with a decrease in energy consumption [24; 25]. That, as we expect, will lead further to a decrease in the degree of polymerisation of cellulose macromolecules during the hydrolysis process and to an increase in its solubility. The main features of cellulose powders that characterise their application are physical inertness, morphology, microporosity of particles and highly developed active surface, which are determined by the degree of polymerisation.

Destruction of cellulose raw material was carried out by exposure to 1.5 N hydrochloric acid solution. This was followed by washing and dewatering operations. To determine the characteristic viscosity and degree of polymerisation of microcrystalline cellulose, the complex compound iron hexanatrium tristartrate, or the so-called iron-amine-sodium complex (IASC), which is a complex of iron with sodium tartrate in sodium hydroxide solution, was used [26].

RESULTS AND THEIR DISCUSSION

Since hemp stalk is a heterogeneous raw material (20 % hemp and 80 % shive), with each part containing a different length of fiber and percentage of cellulose, it is not advisable to grind and cook it in undivided form (Fig. 3, *a*).

Due to the fact that shive contains a small length of fiber and is weakly fibrillated, it is not used in the production of high-quality papers. Therefore, when processing hemp stalks, they are usually utilized as shive briquettes. We believe that the processing of shive into pulp and paper products using traditional technology (sulphate delignification method) is possible for certain types of papers. In this work, the pulp yield from shive after cooking was 38 % (Fig. 3,*b*), lignin content was 2,14 %.

a *b*

Fig. 3.Cellulose extraction from industrial hemp:
a – technical hemp before cooking; *b* – unbleached pulp from technical hemp

To obtain pulp sheet with given mechanical strength characteristics it is necessary to develop a complex of properties in natural fiber such as flexibility, elasticity, strength, which is possible only in the process of its grinding. Table 2 shows mechanical properties of pulp sheet obtained after grinding of industrial hemp (shive) in a disc mill. For comparison, the table presents the norms of State Standard 11208-82 "Wood pulp (coniferous) sulphate unbleached, NS-3 grade" [27].

Table 2
Mechanical properties of pulp sheet

Grinding degree according to the Shopper-Rigler scale	Breaking length, km	Resistance	
		to pressure, kPa	to tearing, gs
15	2,8	121,2	18,4
57	8,2	385,4	65,3
HC-3 (60)	7,8	–	64,0

As can be seen from the table, the mechanical properties of pulp sheet made of unbleached cellulose extracted from the shive at the grinding degree of 57 ºShR on the Shopper-Rigler scale correspond to the indicators of State Standard 11208–82 for the manufacture of wet strength paper, base paper for the inner layers of decorative laminates, cardboard for the end covers of filter elements, in contrast to pulp sheet at the grinding degree of 15 ºShR. Thus, at grinding degree 57 ºShR breaking length and resistance to tearing are close in values to the corresponding indicators of State Standard 11208–82. The index of resistance to tearing for NS-3 grade is not regulated. This is explained by the fact that, the ability of fibers to form inter-fiber bonding forces in the development of external and internal fibrillation of fibers increases in the process of grinding of fibrous mass. This is due to the fact that the grinding process in the blade machines is characterised by two factors: hydrodynamic and mechanical. These factors have an impact on the fibers during the passage of fibrous suspension through the working inter-blade cavity formed in the plane of conjugation of the stationary stator element with the rotating rotor one. The hydrodynamic effect is associated with factors that can be divided into several groups [28; 29]:

– modes of movement of fibrous suspension stocks of different concentration in interblade grooves of grinding cavity, determining its properties and character in the process of passing the cavity depending on the head and speed of stock;

– cavitation effect caused by the phenomenon of emergence, development and, under certain conditions, collapse of cavitation bubbles in the liquid phase interacting with fibrous material;

– pulsation effect caused by cyclically alternating drops of hydraulic pressure, in the form of its sharp increase and decrease in the suspension to be treated, with simultaneous circulation of pressure and discharge waves through it at the sound speed;

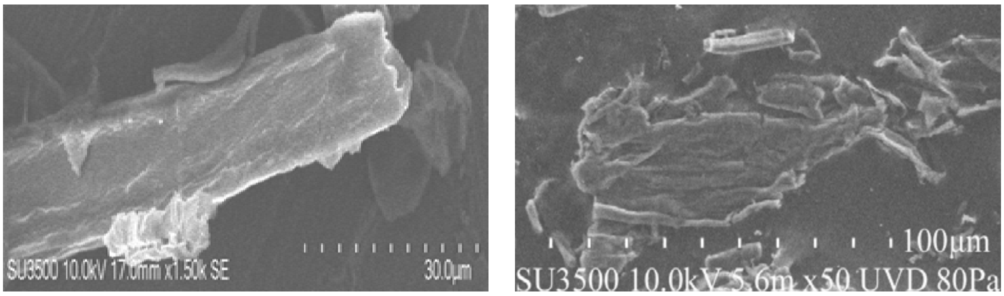
– shock impact caused by collisions of fibrous suspension flows moving relative to each other and their impacts with solid fragments of grinding element [30; 31];

– hydrodynamic friction due to the viscosity of the suspension and the velocity gradient between its layers [32].

Mechanical influence on fibrous material is connected with its complex deformation as a result of compression, torsion, shear stresses applied to it simultaneously. Due to them fibers, respectively, are crushed, split in longitudinal direction, cut and fibrillated, i.e. they become more flexible and plastic [16; 25]. At the same time, when grinding fibrous materials in blade machines with traditional design of working blade surfaces, the share of energy spent in the grinding process on hydrodynamic impact is less significant compared to the energy spent on mechanical impact [29].

It was found [33–36] that the inclusion of powdered cellulose materials in the composition of fibrous mass leads to an increase in the strength bonds between the fibers in the finished paper sheet. Therefore, the fibrous mass was subjected to chemical treatment after grinding, in order to enhance the destruction of the cellulose structure and obtain microcrystalline cellulose from it. Microcrystalline cellulose was obtained by acidic heterogeneous hydrolysis according to the scheme including preparation of hydrolysis solution, hydrolysis of cellulose, washing, drying, dispersing and sorting of the obtained cellulose powder [26]. Hydrolysis (chemical treatment) of cellulose samples after grinding was carried out at temperature t = 85 ºC, in the presence of 1.5 N hydrochloric acid HCl, at hydrolysis plant for 75 minutes. The analysis of experimental data showed that with increasing the grinding degree of fibrous mass up to 83^0 ScR the degree of polymerisation of microcrystalline cellulose decreases, from 180 to 75.

Electron microscopy images, obtained with a Hitachi SU3500 SEM microscope, illustrating the efficiency of fibrous suspension development after grinding microcrystalline cellulose obtained from shive (industrial hemp) are on Fig. 4.



a *b*

Fig. 4. Electron microscopy image of microcrystalline cellulose obtained from shive:
a – image of microcrystalline cellulose at 15ºShR; *b* – image of microcrystalline cellulose at 83ºShR

As can be seen from the images, not only the increase of fiber outer surface after grinding of fibrous suspension occurs, but also the destruction of intermolecular bonds inside the cell wall of fiber with the formation of microcracks happens. All this leads to an increase in the rate of reaction of fibrous suspension with acid and a decrease in the degree of polymerisation of powder cellulose.

CONCLUSION

Thus, as a result of the conducted research:

– Plant polymers from annual plants (industrial hemp shive) are good raw materials for the production of certain types of papers and microcrystalline cellulose;

– It was found out that for obtaining finished products in the pulp and paper industry from annual plants, a very important role is played by the process of grinding of fibrous materials, especially in obtaining microcrystalline cellulose;

– The use of fibrous suspension pre-treated on a disc mill allows to reduce the costs of further chemical treatment in the process of obtaining microcrystalline cellulose.

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