Effect of terms and conditions of cutting propagation on the rooting of coniferous trees

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Abstract. The Irkutsk region has large forests. They occupy 83% of the territory and amount to more than 11% of the total Russian forests. The active production growth has a negative impact on the environment. Every year, millions of hectares of forest are cut down for the production needs. 14.1 million m^3 of wood was harvested only during January-June 2022. Most of the harvested wood is coniferous. Therefore, the need for high-quality planting material is growing every year. The problem of reforestation can be solved by creating a technology for cutting propagation of the main coniferous trees. Our research was devoted to the study of the effect of various terms of propagation of the family Pinaceae representatives by softwood cutting and the conditions for its realization on the yield of planting material. Cutting harvesting was carried out in four terms: from the third decade of June to the end of July. Different conditions were used for cutting propagation: a greenhouse with a mist irrigation system and a climate chamber with manual watering. The study showed that the cuttings planted in the third decade of June into the greenhouses with the controlled mist irrigation systems are characterized by powerful roots.

1 Introduction

Forest ecosystems are the most economical. In addition to providing raw materials for industry and a sufficient amount of oxygen, they are also carbon dioxide accumulators [1]. Therefore, the forest industry can be said to be one of the main foundations of the green economy and forestry – the main type of land use [2]. Raw materials from coniferous trees are most valued all over the world. In the Irkutsk region, the largest area is occupied by pine forests (15.5 million hectares), followed by larch forests. The region is also represented by cedar, spruce, and fir forests. The natural process of renewal of coniferous tree species is long and difficult to predict [3]. The main disadvantage of the propagation by seeds is that they often have a forced dormant period, seedlings develop slowly (especially in the first few years of life) [3-6]. According to Federal State Statistics Service in the Irkutsk Region (Irstat), up to 15 thousand hectares of forest are subject to artificial reforestation annually. On account of the growth of logging activities and regular fires (especially in remote and protected areas),

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the demand for high-quality and improved planting material is increasing. Most reforestation companies use tree seedlings obtained by seed propagation, the main disadvantages of which are the preservation and transmission of accumulated infections to offspring and the spontaneity of the hereditary information distribution with the preservation of the genetic diversity. Vegetative propagation is important for maintaining the genotype of plus trees, especially in areas with high anthropogenic load (near cities, railways and industrial enterprises). Vegetative propagation is applicable in plant breeding and seed production to create clonal seed plantations used to obtain seeds with increased genetic qualities [7, 8]. Improved vegetative propagation systems make cumulative propagation of individual clones in a wider selection of species possible [9]. One of the most common methods of vegetative propagation is softwood cutting propagation. The method is based on the natural ability of plants to regenerate lost organs or parts, to form whole plants from stem cuttings [10]. The root formation ability depends on many factors: from the age of the mother plant, its condition (presence or absence of non-infectious and infectious lesions, weakness caused by pests) to the conditions of cutting propagation and rooting [11]. Vegetative propagation increases the yield of high-quality seedlings for the production of planting material for forestry. The selection and mass propagation of individual trees has advantages for the reforestation productivity [12].

2 Objects and methods of research

The research was carried out in 2019-2022in the territory of Siberian Institute of Plant Physiology and Biochemistry of the Siberian Branch of the Russian Academy of Sciences (Irkutsk, Irkutsk region) in greenhouse conditions and the Phytotron artificial climate station. The research was carried out using the equipment of the Center for Collective Use ‘Bioanalytics’ and the collection material of the Center for Collective Use ‘Bioresource Center’of Siberian Institute of Plant Physiology and Biochemistry of the Siberian Branch of the Russian Academy of Sciences (Irkutsk).

The research objects were the pine family (Pinaceae) representatives (Pinussylvestris L., Piceaobovata Ledeb., Piceaobovata var. coerulea Malyschev., Pinussibirica Du Tour) growing in the territory of the collection site of the Center for Collective Use ‘Bioresource Center’ of Siberian Institute of Plant Physiology and Biochemistry of the Siberian Branch of the Russian Academy of Sciences (Irkutsk). Regular methods of agronomy and forestry were used [13, 14]. Statistical processing of the research results [14] was carried out using the Excel 2010 computer program. When evaluating the reliability of the research, the LSD05 indicator was calculated (least significant difference for multi- and single-factor experiments). The graphs used a correlation trend line.

The purpose of the research was to evaluate the technology of coniferous tree rooting (the summer period of cutting propagation).

The objectives of the research included determination of the optimal terms for cutting propagation of coniferous trees; selection of favorable conditions for rooting the cuttings and effective ways for preparing the cuttings.

3 Conditions and methods of research

Rooting of the cuttings was carried out: in a polycarbonate greenhouse made of a galvanized metal profile covered with 6 mm polycarbonate honeycomb with the installation of a controlled mist irrigation system in propagation beds; in the Phytotron climate station – in plastic boxes for cutting propagation (30x20x15) with manual watering. A mixture of peat and river sand (3:1) with an acidity of 6.0 to 6.2 was used as the soil (measurements were made with a pH meter).Before planting, the soil was treated with a saturated solution of potassium permanganate. The plantings were mulched with sand (2-3 cm). Before the cutting propagation, the beds were prepared as follows: firstly, drainage was laid on the bottom, then 40 cm of shredded coniferous branches and needles, then 10-12 cm of the prepared soil. In the boxes for cutting propagation, the drainage was no more than 2 cm, the same amount of shredded coniferous branches and needles, and then the soil mixture.

Spruce trees reach their maximum growth when the average daily temperatures are +20°C [15]. In the Irkutsk region, such temperature settles after June 20; by the end of July the growth rate of shoots fades. During immediately that period, the cutting propagation began (June 20, July 1, July 10, July 20). The propagation terms were 2-3 days. According to Talbert et al. (1993) [9], Joseph Riov et al. (2020) [2], vegetative propagation (including cutting propagation) from physiologically mature plants is very difficult. Due to that, the cuttings were harvested from 10-20-year-oldplus plants without signs of a pest infestation, as well as without infectious and non-infectious diseases [16]. 100 cuttings per variant were planted in triplicate. The current-year shoots were taken for the cuttings. The harvesting was carried out in the morning. The cutting length was up to 10-12 cm. The preservation of the whorl of the cutting was a must. The cut down cuttings were placed in vessels with water at room temperature for 18-24 hours. The cuttings were soaked in a room protected from light at room temperature [13]. Before planting, the cuts were refreshed with a pruner. 2 cm of the lower part was then dipped into a container with Kornevin (indolylbutyric acid (IBA) at a concentration of 5 g / kg). Next, the excess was shaken off, and the cuttings were planted in the soil (3-4 cm of depth). Root formation stimulants have a positive effect on the rooting of cuttings of coniferous species [6, 17]. For the control, untreated with Kornevin but only soaked in water cuttings were planted nearby. The wall of the chamber and greenhouse were shaded with covering material so that direct sunlight did not fall on the planted cuttings. Shading has a positive effect on rooting [10, 18].

Protective covers made of film were put on the boxes in the climate chambers, to create the greenhouse effect [13]. The watering was manual in the form of aerosol spraying. In the greenhouse, watering was automatic with the help of mist. That made it possible not only to maintain the necessary humidity of the air and soil, but also to reduce the air temperature during hot days. The chamber and the greenhouse were aired. When compacted, the upper soil layer was loosened by forking. When necessary, the beds were weeded. At the end of August (the cutting propagation year), the first records of rooting and survival of the cuttings were carried out, the dead plants were removed (Figure 1).

From mid-September to mid-October, the plants were root watered when the soil dried out at a depth of 1.5-2 cm. During that period, the soil temperature decreased to +10°C and below. Under such conditions, the rooting intensity noticeably decreases [19]. For the winter, when the top soil layer froze up (end of October – beginning of November), the cuttings were mulched with half-rotted sawdust 15-20 cm high (imitation of snow). In spring (April), when night temperatures rose to –5°C, the sawdust cover was gradually removed. The second rooting evaluation was carried out in mid-June of the following year after the cutting propagation. At this stage, both the formation of callus or roots and the presence or absence of vegetative growth were taken into account. The third rooting evaluation was carried out at the end of August. The number and length of first order roots (cm), the number of roots (pieces), the average root length (cm) [20], and the length of vegetative growth (if any) weremeasured on the rooted cuttings.

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a) b)

Fig. 1. Cuttings of Piceaobovata (a), and Piceaobovata var. coerulea (b) in cultivation beds after winter.

4 Results and discussion

Cuttings treated with the Kornevin root formation stimulant were planted to study the effect of the root growth stimulant on the root formation of coniferous cuttings. The results were then compared with those of theuntreated cuttings. The survival rate of theuntreated cuttings was equal to zero. The cuttings treated with Kornevin rooted unevenly. The results are shown in Table 1.

The research results were analyzed according to the analysis of variance for a two-factor experiment. The first factor (A) was the cutting propagation terms; the second factor (B) was the cutting propagation conditions (greenhouse/ chamber). Based on the results of the two-factor experiment data, the significance of the effect of factor A (cutting propagation terms) and factor B (cutting propagation conditions) was noted since the calculated value of the Fisher criterion exceeded the tabular one. The multi-factor statistical analysis showed the significant dependence of the result on factor A (5.38%). The determination of factor B showed the dependence on the factor by 15.4%. In the experiments of M. I. Dokuchaeva [13], the rooting rate of Scots pine cuttings was from 1 to 2%. In the present research, the rooting rate of the genus Pinus trees was also low and amounted to less than 1% (0.75% for Pinussylvestris and 0.5% for Pinussibirica in the greenhouse with the mist irrigation system and equal to zero in the climate chamber) (Table 1).

The rooting was observed in 1 out of 100 cuttings harvested in the 3rd decade of June and 3rd decade of July. No rooted cuttings were observed in the second and first decades of July. The best picture was observed in the genus Picea representatives. Thus, the rooting of the Piceaobovata cuttings in the greenhouse averaged 30.9%; the rooting of the Piceaobovata var. coerulea cuttings was 22.3%. The worst results were observed in the climate chamber: the rooting of Piceaobovata cuttings was observed only in the propagation term of the second decade of July and amounted to 5%. The rooting of the Piceaobovata var. coerulea cuttings was observed in those harvested in the first and second decades of July (1 and 2%). The rest of the variants were equal to zero. The dependence of spruce rooting on the cutting propagation terms is shown in Figure 2.

Table 1. The effect of cutting propagation terms on the rooting of cuttings of studied coniferous species seedlin gs treated with the root formation stimulant Kornevin for the period 2019-2020.

No.	Research object	Cuttin g propa-gation date	Cutting propa-gation conditions	Survival, %	Rooting, %	Number of roots, pcs	Average root length, cm
1	*Piceaobovata* Ledeb.	June 20	1	72.0	31.5	4.2±0.41	22.2±2.64
			2	0.0	0.0	0.0	0.0
2	*Pinussylvestri s* L.		1	14.0	1.0	1.0±0.40	0.5±0.08
			2	23.0	0.0	0.0	0.0
3	*Piceaobovata var. coerulea* Malyschev		1	37.0	28.0	2.2±0.75	21.8±10.23
			2	0.0	0.0	0.0	0.0
4	*Pinussibirica* Du Tour		1	31.0	1.0	1.0±0.20	0.3±0.02
			2	12.0	0.0	0.0	0.0
1	*Piceaobovata* Ledeb.	July 1	1	40.0	28.0	4.5±0.84	17.7±4.08
			2	9.0	0.0	0.0	0.0
2	*Pinussylvestris* L.		1	6.0	0.0	0.0	0.0
			2	0.0	0.0	0.0	0.0
3	*Piceaobovata var. coerulea* Malyschev		1	30.0	18.0	2.0±1.55	15.0±6.87
			2	18.0	1.0	1.0±0.18	0.2±0.03
4	*Pinussibirica* Du Tour		1	13.0	0.0	0.0	0.0
			2	1.0	0.0	0.0	0.0
1	*Piceaobovata* Ledeb.	July 10	1	53.0	30.0	4.2±1.72	13.3±3.08
			2	56.0	5.0	2.3±1.02	12.2±2.64
2	*Pinussylvestris* L.		1	25.0	1.0	1.0±0.03	0.3±0.05
			2	0.0	0.0	0.0	0.0
3	*Piceaobovata var. coerulea* Malyschev		1	51.0	17.0	2.8±1.60	10.2±3.82
			2	17.0	2.0	1.0±0.05	0.2±0.01
4	*Pinussibirica* Du Tour		1	44.0	0.0	0.0	0.0
			2	0.0	0.0	0.0	0.0
1	*Piceaobovata* Ledeb.	July 20	1	65.0	34.0	4.3±1.03	19.8±4.67
			2	0.0	0.0	0.0	0.0
2	*Pinussylvestris* L.		1	46.0	1.0	1.0±0.02	0.2±0.07
			2	23.0	0.0	0.0	0.0
3	*Piceaobovatavar. Coerulea* Malyschev		1	39.0	26.0	2.3±1.03	17.3±10.42
			2	0.0	0.0	0.0	0.0
4	*Pinussibirica* Du Tour		1	40.0	1.0	1.0±0.02	0.2±0.01
			2	12.0	0.0	0.0	0.0
main effects of factor A					LSD05 3.7		Ff≥Ft
main effects of factor B					LSD05 8.3		Ff≥Ft

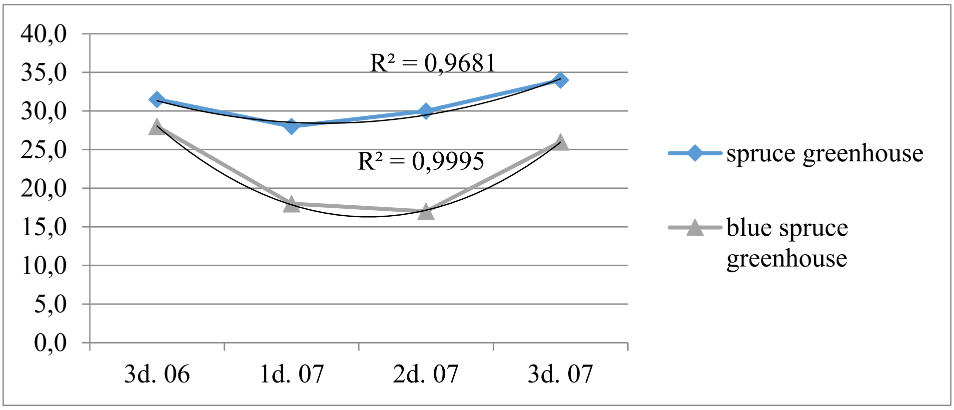


Fig. 2. Dependence of the number of the rooted spruce cuttings in the greenhouse with the mist irrigation systems on the terms of the cutting propagation, LSD05 1.37.

A higher percentage of the rooted cuttings was observed in the 3rd decade of June and the 3rd decade of July. The largest number of the rooted cuttings (34%) was in *Piceaobovata* plants in the third decade of July. *Piceaobovata var. coerulea* showed a higher percentage of rooting (28%) in the third decade of June. In the experiments of N.V. Pinaeva (2015) [16], the rooting rate of *Piceaobovata* was 20%; in the experiments of M.I. Dokuchaeva [13] it was up to 40%. According to Canadian researchers, up to 80% of cuttings rooted in peat-humus-sandy soil in a greenhouse [21]. The results obtained do not contradict previous domestic studies in other regions.

Two ways of preparing the cutting for planting are described: free from needles in the basal part and not free ones [13]. In our research, variants with and without cleaned cuttings were included to compare the effectiveness of such methods of cutting preparation. The research results showed that the rooting of cuttings with preserved needles is 10% higher (Table 2).

Table 2. Effect of needle removal from cuttings on rooting.

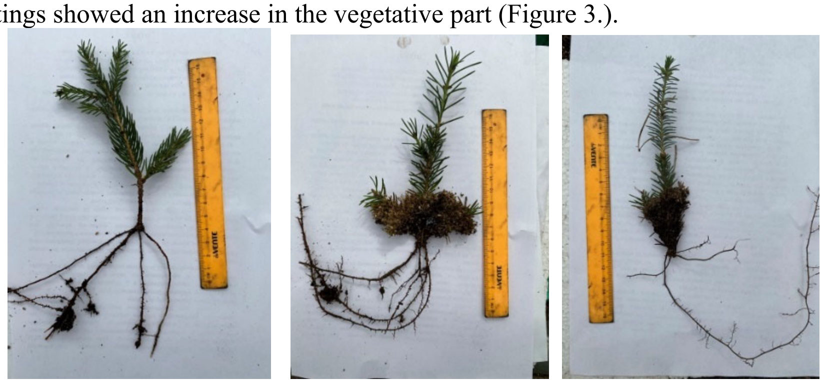
Treespecies	Variant	Rooted cuttings, %			Average rooting, %	LSD05	Rooting terms, days
		1	2	3			
Piceaobovata	without needles	10	6	8	8.00±2.00	12.25	186
	with needles	17	22	16	18.33±3.21		155
Piceaobovata var. coerulea	without needles	2	3	4	3.00±1.00	7.98	186
	with needles	8	14	16	12.67±4.16		155

According to the one-way analysis of variance, a significant effect of the method of preparing cuttings on their rooting was noted since the calculated value of the Fisher criterion exceeded the tabular one.

The cuttings with removed needles rooted during a longer period; they die more often. The rooting time for the cuttings without needle removal is 20 days shorter than that for the cuttings with removed needles. For the first time, the rooting was evaluated in August of the cutting propagation year. According to the evaluation, the major dying-out of plants was observed; neither roots nor callus tissue were seen on them. The survival, i.e. the number of the cuttings that preserved the living and healthy parts, was calculated. More than 90% of the dead cuttings accounted for that period.

The second rooting evaluation took place in June and August of the following year. Only in August, the plants with the already developed root system were found. As a result, it can be said that it takes more than 155 days for coniferous plants of the *Pinaceae* family to root in Cisbaikalia. To obtain good quality seedlings with a high yield percentage, it is better not to remove needles from cuttings before planting. This manipulation requires additional energy and labor costs, while excessively injured cuttings are more susceptible to infections and die more often. During early spring cutting propagation in the Tomsk region [6], plants of the genus *Picea* begin to form roots in 75–80 days. During summer cutting propagation [13] in the Moscow region, roots are formed in 66–80 days. According to the research results for Cisbaikalia, the rooting formation period is longer.

To determine the rooting quality, biometric indicators of the formed roots were measured. Figure 3 shows the quality of the root system of spruce cuttings with different preparations. At the time of measurement, all the survived cuttings had roots of good quality, and most of the cuttings showed an increase in the vegetative part (Figure 3.).



a) b) c)

Fig. 3. The rooted cutting of Piceaobovata with the removed needles (a), without the needle removal (b), the rooted cutting of Piceaobovata var. coerulea without the needle removal (c).

The roots were more often formed near the whorl and less often along the line of the lower cut of the cutting from its central part. They were brown, with white subulate tips; most of them had small roots of the second order, and less often – of the third. The beginning of the vegetative part growth was observed in late May - early June (no root formation was observed during that period), which corresponded to the beginning of seasonal vegetative growth for plants in open ground. By the time of the measurement (August), the growth was from 6 ± 0.13 to 11 ± 1.02 cm. Regardless of the cutting propagation term, the number of roots in *Piceaobovata* varied from 1 to 5. The plants with 4 roots prevailed in the seedlings from the propagation beds (4.3±0.14 pieces). The number of *Piceaobovata var. coerulea* roots also varied from 1 to 5, but most of the cuttings had 2 roots (2.33±0.34) (Figure 4).

In the seedlings from the boxes, a smaller number of roots were noted, but they were more branched and had a greater number of secondary roots. The central roots had a curved shape. Their average number was 2.35±0.38 pieces in *Piceaobovata*. In *Piceaobovata var. coerulea,* that number was 1.3±0.22 pieces. The results of the multi-factor analysis of variance showed that the cutting propagation conditions do not affect the number of roots in the cuttings since the calculated value of the Fisher criterion is lower than the tabular one. The determination of factor A (cutting propagation terms) has a low percentage of dependence (1.17%). The value of the calculated Fisher criterion is close to the tabular one.

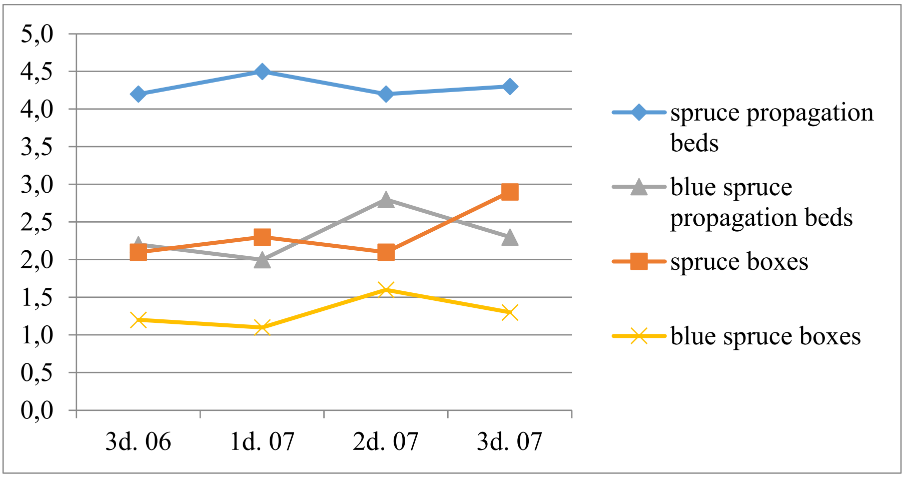


Fig. 4. Change in the number of spruceroots during the growing seasons 2019-2022, depending on the cutting propagation terms, pieces. LSD05 of factor A is 2.77. LSD05 of factor B is 2.26.

In the propagation bed, the root system is freely located in the soil. That makesmore intensive growth possible. The quality of the root system of the cutting seedlings from the boxes differed from the roots formed in the propagation bed. Under such conditions, longer roots were noted in the cuttings planted in the third decade of June. They averaged 22.2 cm for *Piceaobovata* and 21.9 cm for *Piceaobovata var. coerulea* (Figure 5). The shortest root length was noted in the cuttings rooted in the second decade of July (13.3 cm and 10.2 cm, respectively).

In the boxes, longer roots were noted in the cuttings planted in the third decade of June. They averaged 12.3 ± 1.61 cm in *Piceaobovata* and 11.6 ± 1.79 cm in *Piceaobovata var. coerulea* (Figure 5). *Piceaobovata* cuttings rooted in the second decade of July showed the shortest root length (8.6 ± 1.25 cm). *Piceaobovata var. coerulea* cuttings from boxes showed the shortest root length in two terms (the second and third decades of July). It was 7.8±1.06 cm. The results of the multi-factor analysis of variance showed that the cutting propagation conditions had little effect on the root length of the cuttings. The more significant effect was noted for factor A (cutting propagation terms). The determination of factor A was 26.81%. The value of the calculated Fisher criterion is higher than the tabular one.

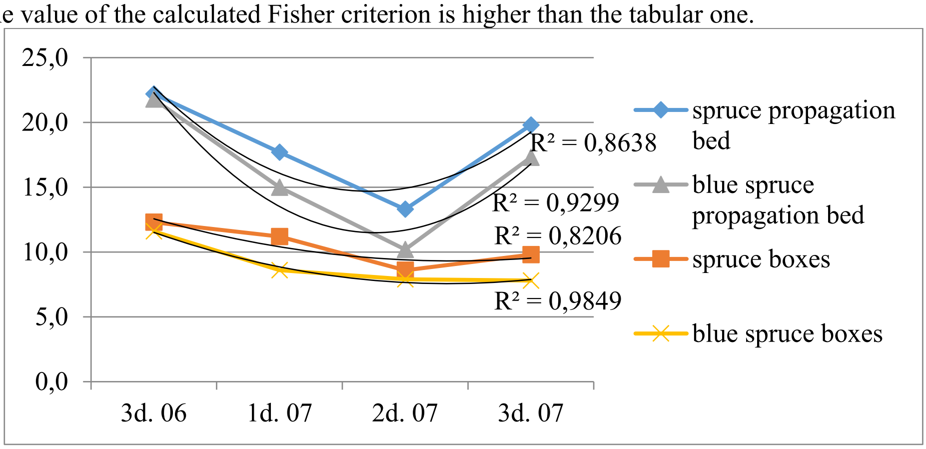


Fig. 5. Change in the length of spruceroots depending on the cutting propagation terms, cm. LSD05 of factor A is 17.91. LSD05 of factor B is 14.62.

5 Conclusion

The cuttings treated with the root formation stimulant ‘Kornevin’ have a high percentage of rooting compared to the untreated ones.

The conditions created for the cuttings in the greenhouse with the mist irrigation system have the advantage over the conditions in the climate chamber with the manual watering.

Plants of the genus *Pinus* showed the worst results. The rooting rate of softwood cuttings was less than 1% (0.75% for *Pinussylvestris* and 0.5% for *Pinussibirica*). The best resultswere observed in the genus *Picea*representatives. Thus, the rooting of the cuttings in the greenhouse averaged 30.9% in *Piceaobovata* and 22.3% in *Piceaobovata var. coerulea*.

The results of the experiment showed that the best term for the cutting harvesting is the 3rd decade of June and the 3rd decade of July.

When preparing the cuttings for planting, the worst variant was the one where the needles were removed from the cuttings; the rooting percentage of such cuttings is lower, and the rooting period is longer.

In Cisbaikalia, more than 155 days are required for the rooting of coniferous plants of the *Pinaceae* family.

The cuttings planted in the third decade of June in the propagation beds withthe mist irrigation system are characterized by vigorous roots. Their length averaged 22.2 cm for *Piceaobovata* and 21.9 cm for *Piceaobovata var. coerulea*.

The research was carried out using the equipment of the Center for Collective Use ‘Bioanalytics’ and the collection material of the Center for Collective Use ‘Bioresource Center’ of Siberian Institute of Plant Physiology and Biochemistry of the Siberian Branch of the Russian Academy of Sciences (Irkutsk).

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