Innovative aspects of cultivation of large spruce seedlings for reforestation

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Abstract. Studies conducted in a forest nursery (Moscow region, Russia) have established the following. Seeds, additionally sorted by size and weight, should be used for the cultivation of large spruce seedlings (*Picea abies* (L.) H. Karst.). Lightweight seeds must be removed. Only heavy and medium weight seeds should be used for sowing. When sowing, the seeds must be distributed uniformly in the sowing line with the same distance between them. The rate of sowing of spruce seeds should ensure the optimal plant density in the sowing line in the amount of 20-30 pieces per meter. Horizontal pruning of spruce seedling roots must be carried out at a depth of 12-15 cm at the age of three in the second half of July. This enables to form a fibrous root system and developed crown of plants. Innovative technology of cultivation of large spruce seedlings in the sowing section of the nursery enables to get planting material which is similar to transplants.

1. Introduction
The main indicator of planting material, which is prepared for reforestation, is its height. The height should be not less than 12 cm [1, 2]. Transplants are the priority planting material for reforestation. They require less agrotechnical care and survive better in the plantation area. The technology of growing spruce transplants (in the first step) involves growing seedlings in the sowing department of the nursery with subsequent outplanting and transplanting for growing. This method of growing large-scale planting material requires significant labor costs [1, 2]. In addition, the quality of planting material grown in this way does not fully meet modern requirements. Such planting material has an excessively developed root system and great crown. This complicates mechanized landing and negatively affects its quality. Advanced technologies for growing planting material make it possible to obtain large seedlings of Norway spruce in the sowing section of a nursery. These seedlings are similar to transplants. They have fibrous root system and compact, developed crown [1, 2]. The agrotechnical methods of cultivation of large spruce seedlings provide the use of sowing seeds. They are sorted by size and weight with subsequent uniform placement in the sowing line and pruning of the root systems in the process of seedlings growing. Performing these technological operations reduces labor costs in comparison with transplant cultivation and improves its quality [3-6].

The aim of the study was substantiation of the innovative approach to the growth of large spruce seedlings (*Picea abies* (L.) H. Karst.) in the sowing section of the nursery. The seedlings are similar to transplants.
2. Materials and methods
The objects of the research were local seeds of Norway spruce from one batch of 1 (the best) quality class harvested in local territories, as well as biennial and three-year-old spruce seedlings grown in the sowing section of the nursery (Moscow region, Russia). Studies were conducted during the 3-year vegetation periods. 10 kg of seeds were used for the experiments and analysis of germination energy and soil germination. All the seeds were divided into 9 groups: 3 fractions by size on sieves with round holes (large, medium and small). Each group of these fractions was divided into 3 by weight (heavy, medium and light). Each of the 9 groups of seeds was sown on a separate seed belt. Seedlings grown from the seeds were dug out; the roots were washed to remove the soil, measured and dried to air dry condition. After that, the mass of plant parts (needles, tender roots) were analyzed. The parametric indicators of seedlings were studied during observations: average diameter and average height, as well as the ratio of the mass of tender roots to the mass of the needles. The number of repetitions of the experiments was adopted as 5. The total number of seedlings taken for the analysis was 1000 pieces.

The most important indicator of the quality of planting material for reforestation is its height, since larger planting material is less susceptible to the negative impact of weeds. Currently, transplants are used as a large-scale planting material for reforestation.

The technology of growing spruce transplants involves (in the first step) growing seedlings in a nursery for two to three years, followed by digging and transplanting for additional growing for another two or three years. This leads to an increase in the cost of cultivated planting material.

Innovative technology of planting material cultivation for reforestation enables to get large seedlings in the nursery which have the same characteristics as transplants [7-11]. A 5-row sowing scheme with a spacing of 22.5 cm between sowing lines is recommended for nurseries with sandy and loamy soils.

In this connection, substantiation of the innovative approach to the growth of large spruce seedlings in the sowing section of the nursery is of particular interest. The primary task in the cultivation of large spruce seedlings is to ensure uniform distribution of seedlings in the sowing lines with the quantity providing a rational area for their nutrition. An important agrotechnical technique for increasing this indicator is presowing treatment of seeds by separating them into fractions according to the size and weight in order to separate seeds with high soil germination. To do this, the spruce seeds were divided into 3 fractions on sieves with round holes (large - more than 2.5 mm, medium – 2-2.5 mm and small - less than 2.0 mm) using sieves. Then the seeds in each fraction, using the pneumatic separator of forest seeds PLS-5M (OJSC TsOKBleskhozmash, Russia) at an air flow rate of 7…8 m/s, were sorted by weight into heavy, medium and light ones.

3. Results and discussion
Analysis of the obtained results (table 1) shows that soil germination of seeds depends on their size and weight. Heavy and medium-weight seeds of large fraction (over 2.5 mm) have a ground germination rate which exceeds germination of lightweight seeds of this fraction by 1.8-2.3 times. Soil germination of heavy and medium spruce seeds in the small fraction (less than 2.5 mm) exceeds the germination of light seeds by 2.2-2.4 times. For the seeds of the middle fraction (2-2.5 mm), this difference is insignificant and amounts to 1.2-1.5 times. It was established that the largest number of lightweight seeds of spruce (45.7%) was found in the seeds of small fraction, and the smallest number (20.9%) - in the seeds of middle fraction. The amount of lightweight spruce seeds was 28.6% in the seeds of large fraction. The germination energy of light spruce seeds in all the fractions was less than energy of large and medium ones and amounted to 16.5%. For large and medium seeds it was 23.1 and 39.5%, respectively. Thus, the seeds of Norway spruce must be sorted by size and weight before sowing. It is necessary to use heavy and medium-weight seeds of all the fractions for sowing, and it is recommended to remove lightweight seeds.

It is necessary to establish the optimum density of their distribution in the sowing line and identify the feasibility and method of cutting the root systems of seedlings in the process of their growth in justifying the innovative aspects of cultivation of large spruce seedlings. The experiments were
carried out with different density of spruce seedlings in the sowing lines (20-30, 50-60 and 100-110 pieces per meter) in order to substantiate the optimum density. The recommended seeding rate is from 0.5 to 1.5 g/m of the sowing line to obtain uniform germination (it also depends on the quality class of the seeds and the method of their preparation) [1, 2].

**Table 1.** Influence of seed sorting on germinative energy and soil germination.

| Size of seed fraction | Group of seeds by weight | The quantity of seeds in the batch, g | The number of light seeds, in % of the fraction | Germinative energy, % | Soil germination, % |
|----------------------|--------------------------|-------------------------------------|-----------------------------------------------|----------------------|---------------------|
| Large (over 2.5 mm)  | Heavy                    | 54                                  | -                                             | 49.4                 | 50.0                |
|                      | Light                    | 38                                  | 3.1                                           | 28.6                 | 23.1                |
| Medium (2-2.5 mm)    | Heavy                    | 315                                 | 25.4                                          | -                    | 46.7                |
|                      | Light                    | 217                                 | 17.5                                          | 20.9                 | 39.5                |
| Small (less than 2.5 mm) | Heavy               | 18                                  | 1.5                                           | -                    | 50.5                |
|                      | Light                    | 32                                  | 2.5                                           | 45.7                 | 16.5                |

Plantations with various norms of spruce seed sowing were made with a SLN-5A seeder forest mounted (OJSC TsOKBleskhozmash, Russia). The seeder used studied sowing machines that ensure uniform distribution of seeds in the sowing line. Covering of seeds with a mixture of peat and sand (1:1) with a layer of 0.7-1.0 cm is an important technological method, ensuring the appearance of even sprouts. Covering of seeds with the substrate in the sowing lines was carried out by MSN-1A mulcher reticulate mounted (OJSC TsOKBleskhozmash, Russia). After sowing and covering of seeds, the seed rows were mulched with sawdust and rolled. Pruning of root systems of spruce seedlings was carried out to obtain a fibrous root system and compact developed crown. The pruning of spruce seedling roots was made at a depth of 12-15 cm and between the rows at a distance of 10-12 cm from plants. The root cutter mounted universal KNU-1.2 (OJSC TsOKBleskhozmash, Russia) was used for pruning the roots of spruce seedlings, which provided pruning of both horizontal and vertical roots [1, 2].

The obtained biometric and weight indices of three-year-old spruce seedlings grown at different densities of their distribution in the sowing lines, both with and without pruning the roots of plants, are shown in table 2. The analysis of these data shows that the best results were observed with the density of spruce seedlings in the sowing line equal to 20-30 pcs/m. The yield of planting material was at least 800 thousand pcs/ha.

**Table 2.** Sizes and weight of three-year-old spruce seedlings with different distribution density in the sowing line.

| Variant                        | The density of seedlings in the line, pieces/m | The average height of seedlings, cm | Average diameter of seedlings, mm | Air dry weight of 100 pieces of seedlings, g | Ratio, M_T/M_N |
|--------------------------------|-----------------------------------------------|-----------------------------------|----------------------------------|---------------------------------------------|----------------|
| Root pruning                   | 20-30                                         | 35.8                              | 5.6                              | 292.33                                      | 1:3            |
|                                | 50-60                                         | 35.7                              | 5.8                              | 412.71                                      | 1:4            |
| Control (without pruning)      | 100-110                                       | 35.6                              | 4.7                              | 316.35                                      | 1:6            |
| Control                         | 20-30                                         | 30.3                              | 4.6                              | 230.81                                      | 1:4            |
|                                | 50-60                                         | 30.4                              | 4.6                              | 270.62                                      | 1:5            |
|                                | 100-110                                       | 27.7                              | 4.5                              | 257.16                                      | 1:7            |
The most qualitative indicator of planting material is the ratio of the mass of tender roots to the mass of needles $M_T : M_N$. It was established that this ratio was 1:3 in even seeding with a density of seedlings of 20-30 pcs/m and pruning of their roots. It decreased to 1:4 without root pruning. With an increase in the density of seedlings in the sowing line to 50-60 pcs/m, this ratio was 1:4 with the root pruning, and it decreased to 1:5 without root pruning. The average height of seedlings did not change. It was 35.7 cm with root pruning, and it decreased to 30.4 cm without pruning the roots. With a further increase in the density of seedlings up to 100-110 pcs/m, the reduction dynamics of the mass ratio of tender roots to needles mass did not change and decreased to 1:6 and 1:7 respectively. The average diameter of the spruce seedlings changed slightly and amounted to 4.7-5.8 mm in all the variants of root pruning. In the variant without pruning the roots, the average diameter of the seedlings decreased and amounted to 4.5-4.6 mm. It was noted that pruning of roots did not have a significant effect on the growth performances of spruce seedlings in plantations with thicker density.

Pruning of two-year and three-year-old plants was carried out to determine the most favorable age of spruce seedlings for root pruning in the second half of July. The results of the impact of the seedling age on the growth rates when pruning their roots in various ways in the second and third year of cultivation are shown in table 3. The analysis of these data shows that the method of root pruning of two-year-old spruce seedlings with a density of 20-30 pcs/m did not have a significant impact on their growth rates. When horizontal cutting of the roots took place, the average height of spruce seedlings changed slightly and amounted to 11.8 cm. The average diameter was 2.0 mm. The average height of spruce seedlings was 11.1 cm and the average diameter was 1.9 cm with simultaneous pruning of horizontal and vertical roots. The ratio of the mass of tender roots to the mass of needles with these methods of root pruning was 1:2 and 1:3, respectively. With an increase in the density of seedling distribution to 100-110 pcs/m and horizontal root pruning, the average height of spruce seedlings remained practically unchanged and amounted to 11.7 cm. The average root diameter decreased to 1.5 cm. The ratio of the mass of tender roots to the needle mass was 1:3. The average height of the seedlings decreased to 9.7 cm in the variant without pruning the roots. The ratio of the mass of tender roots to the mass of needles decreased to 1:5.

Table 3. The effectiveness of root pruning of two and three-year-old spruce seedlings.

| Seedlings density, pieces/m | Method of root pruning | The average height of seedlings, cm | The average diameter of seedlings, mm | Air dry weight of 100 pieces of seedlings, g | Ratio, $M_T : M_N$ |
|---------------------------|------------------------|-----------------------------------|--------------------------------------|---------------------------------|------------------|
|                           | Two-year-old seedlings  |                                    |                                      |                                 |                   |
|                           | 20-30                   | Horizontal                         | 11.8                                 | 2.0                             | 38.36            | 13.48            | 1:3              |
|                           |                        | Horizontal and vertical             | 11.1                                 | 1.9                             | 38.20            | 25.80            | 1:2              |
|                           | 100-110                 | Horizontal                         | 11.7                                 | 1.5                             | 30.28            | 10.56            | 1:3              |
|                           |                        | Without pruning                    | 9.7                                  | 1.3                             | 25.16            | 5.76             | 1:5              |
|                           | Three-year-old seedlings|                                    |                                      |                                 |                   |                   |
|                           | 20-30                   | Horizontal                         | 35.8                                 | 5.3                             | 292.33           | 100.65           | 1:3              |
|                           |                        | Horizontal and vertical             | 35.0                                 | 6.0                             | 459.31           | 150.77           | 1:3              |
|                           | 100-110                 | Horizontal                         | 35.6                                 | 4.7                             | 316.35           | 63.32            | 1:5              |
|                           |                        | Without pruning                    | 27.7                                 | 4.5                             | 257.16           | 35.63            | 1:7              |
When pruning the roots, the growth rates of three-year-old spruce seedlings were higher than of two-year-old ones. The average height of spruce seedlings with these methods of root pruning and distribution density of 20-30 pcs/m increased significantly and amounted to 35.0-35.8 cm. The average diameter of the seedlings also increased to 5.3-6.0 mm. The ratio of the mass of tender roots to the mass of needles was 1:3. With an increase in the density of seedlings to 100-110 pcs/m and horizontal root pruning, the average height of spruce seedlings and their diameter changed slightly and amounted to 35.6 cm and 4.6 mm, respectively. However, the ratio of the mass of tender roots to the mass of needles worsened and decreased to 1:5.

The average height of Norway spruce seedlings decreased to 27.7 cm, and their average diameter decreased to 4.5 mm in the variant without root pruning. The ratio of the mass of tender roots to the mass of needles decreased significantly and amounted to 1:7.

Thus, root pruning of Norway spruce seedlings is recommended at the age of three. It should also be noted that horizontal root pruning or simultaneous pruning of horizontal and vertical roots did not have a significant effect, both on the average growth rates of seedlings and on the ratio of the mass of tender roots to the mass of needles.

The rational terms for pruning the roots of spruce seedlings during the growing season are determined by special experiments. During the experiments the roots were pruned in late May and in the second half of July. The analysis of the observations (table 4) shows that the average growth of three-year-old spruce seedlings was 9.97 cm, when pruning the roots in May and with a density of 20-30 pcs/m. And it was 10.0 cm when pruning the roots in the second half of July. In addition, when pruning the roots in the second half of July, the ratio of the mass of tender roots to the mass of needles was 1:2. It decreased to 1:4 when the roots were pruned in May.

Thus, the experiments for determination of the optimal terms of root pruning show that it is advisable to trim the roots of three-year-old seedlings in the second half of July.

Table 4. Characteristics of three-year-old seedlings of Norway spruce with different periods of root pruning.

| Seedlings density, pieces/m | Time of root pruning | The average growth of seedlings, cm | Air dry weight of 100 pieces of seedlings, g | Ratio, $M_T/M_N$ |
|----------------------------|----------------------|-----------------------------------|---------------------------------------------|-----------------|
|                            | Pruning in May       | 8.97                              | 96.87                                       | 25.07           | 1:4             |
|                            | Pruning in July      | 10.0                              | 76.26                                       | 40.26           | 1:2             |

4. Conclusions

It is necessary to sort the seeds by size and weight for the cultivation of large seedlings of Norway spruce. Heavy and medium-weight seeds should be used for sowing. Lightweight seeds should be separated. Sowing must be carried out with an even distribution of seeds in the sowing line and seeding rate, ensuring the density of plants in the amount of 20-30 pieces per meter. It is necessary to carry out a horizontal pruning of the roots in the second half of July at a depth of 12-15 cm to obtain fibrous root system and compact crown when growing large seedlings of Norway spruce. The pruning is made in three-year-old seedlings.

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