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Comparative Analysis of Economic Aspects of Growing Seedlings with Closed and Open Root Systems: The Experience of Russia

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Abstract: An intensive increase in the area of clear-cutting on the territory of Russia leads to the growth of non-reforested areas. Therefore, successful reforestation requires higher attention and the use of new technological solutions for growing seedlings. The purpose of this work was to perform an economic assessment of the costs required for traditional and innovative technologies in growing seedlings of woody species with open and closed root systems under different cultivation conditions. The results of the comparative analysis showed that seedlings grown with closed root systems without heating in greenhouses in one rotation require minimum costs for growing. An increasing number of rotations in growing seedlings with closed root systems leads to a decrease in the production costs and makes seedlings of English oak competitive in price with seedlings grown by traditional technology. It has been established that the discounted ROI period for seedlings with a closed root system is 5.5 years. Hence, the transition to innovative technologies for the cultivation of forest planting material is necessary for the effective implementation of recreation processes for forestry of Russia.

Key words: Reforestation, open-rooted seedlings, closed-rooted seedlings, cost of growing forest crops, production costs.

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Introduction

The issues of improving the quality of reforestation are of high relevance in Russian forestry management and their solution is specified by evaluating the effectiveness of existing reforestation methods in terms of forestry and the economy. Since 2011, the area of clear-cutting in the Russian Federation (RF) exceeds the area where reforestation is carried out (Blumroeder et al., 2019). In recent years, the accumulated area of non-regenerated cuttings amounted to about 0.5 million hectares.

A great influence on the success of the subsequent natural reforestation is caused by the technology and machinery used during logging. Of particular importance is the layout of skidding tracks (Rudov et al., 2019), which, in turn, depends on the development and quality of the road network (Kozlov et al., 2019) and the degree of the negative impact of forest machines on the soil (Cambi et al., 2015; Grigorev et al., 2014a). These factors influence the efficiency of forest management as a complex of measures for the harvesting and restoration of forest resources (Grigorev et al., 2014b).

Significant climatic changes determine the need to develop accelerated reforestation methods, including planting tree species that are more stress-resistant (Grigorev et al., 2014c). Such measures are quite challenging for forestry and silviculture that are traditionally focussed on natural reforestation in most regions of Russia.

According to the report of the Federal Forestry Agency (n.d.), reforestation was carried out on an area of 1,127.4 thousand hectares in 2019. Of these, artificial reforestation was performed on an area of 180.2 thousand hectares, which is 17% of the total scope of work (Figure 1).

Contemporary reforestation studies have been done to actively develop the techniques of growing seedlings with a closed root system (CRS). These technologies allow reducing the time of cultivation twice, providing the possibility to plant seedlings throughout the year (Morkovina et al., 2015). Forest regeneration using CRS seedlings demonstrates a high level of plant establishment (Pisarenko, 1979). Forest growing techniques and methods of cultivating forest seedlings with closed root systems have been considered in many works (Kim et al., 2020; Sanchez-Aguilar et al., 2016; Thomas et al., 2016). Much of the research in recent years focus on methods and technical solutions for planting forest seedlings (Sung et al., 2019; Thiffault et al., 2012). According to the findings of these works, planting forest seedlings is the most labour-intensive stage in the general cycle of silvicultural works, and a successful transition to new technologies requires the creation of new planting mechanisation means to be ensured.

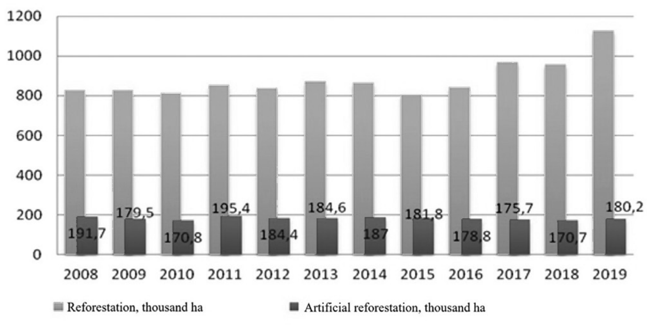

Figure 1: Dynamics of natural and artificial reforestation (in thousands of hectares) for the period 2008–2019 in Russia (Federal Forestry Agency, n.d.).

The means that currently exist in Russia for small-scale mechanisation of planting seedlings grown with closed root systems in containers of various types are not enough efficient, unfortunately, and are limited in terms of practical use (Novikov et al., 2019; Shorohova et al., 2019). The study of technological regime effects on the growth of seedlings allows establishing the optimal woody species for container cultivation.

The technology of growing seedlings with a closed root system implies that the seeds are sown into specially prepared cassettes with a nutrient mixture, in which they grow up to a standard size during the season. Cultivation of seedlings in cassettes allows increasing the possible planting time on a permanent place and providing the best growth of seedlings in the first period after transplanting with the help of a correctly selected nutrient mixture. Researchers note the importance of such factors as seed quality, planting time, and soil moisture for containerised seedling cultivation (Hahn, 1981; Stein et al., 1975).

In world practice, the most common technology is the cultivation of annual seedlings, mainly conifers (pine, spruce). Stein notes that seedlings of southern pine grown with a closed root system are a good alternative to traditional ones due to the short growth period, and consequently, lower costs (Stein and Owston, 1977). Moreover, the closed root system technique provides an advantage in containerised seedlings and less stress during transplanting (Grossnickle and El-Kassaby, 2016). This practice is also used for deciduous species (Pike et al., 2018). Containerised systems produce seedlings with a lower shoot-to-root ratio and greater root growth potential, preventing seedlings from drought

(Grossnickle and El-Kassaby, 2016). In addition, when evaluating stress tolerance and seedling nutrition, the formation of a plug in the container, acting as a source of water and nutrient supply for planting, ensures a higher survival rate under field conditions.

Despite the existence of numerous proofs for the advantages of the closed root system seedling growth technology, it is not widespread in Russia primarily because of the high cost of growing planting material. To date, growing forest seedlings in an open ground or open root system (ORS) is still a widely practiced technology in Russia. According to industry reporting by the Federal Forestry Agency (n.d.), an increase in the number of seedlings with closed root systems has been observed since 2011, but their share in the total volume of seedlings does not exceed 10% (Figure 2). Besides, according to the data shown in Figure 2, there has been a 30% decrease in the rate of seedling growth over 10 years.

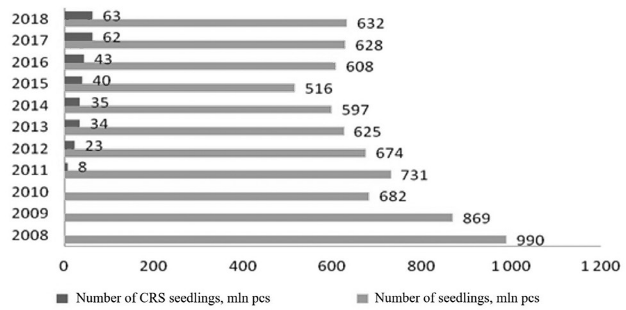

Figure 2: The number of coniferous seedlings grown per year using closed-root or open-root technologies for the period 2008-2018 in the Russian Federation.

Hence, the successful implementation of a new methodology for growing seedlings can minimise production costs and increase productivity. The accounting data on the costs of growing seedlings can be used to assess and analyse the work of forestry enterprises and determine the financial results of their activities. In recent years, certain progress has been made in the cultivation of closed root system seedlings. Thus, a significant part of manual work has been mechanised and automated, and greenhouse complexes for growing containerised seedlings have been built in different country regions. Also, different tree species and seeds are being actively investigated (Dumroese and Landis, 2015; Marx et al., 1982; Vieira et al., 2019).

These circumstances predetermine the necessity of economic substantiation of expediency for growing seedlings with closed roots. The purpose of this work was to perform a comparative analysis of the economic aspects of traditional and innovative technologies for growing seedlings of woody plants. Economic assessment of costs was carried out by comparing the expenses required for growing seedlings of English oak in containers or open ground to achieve a standard size. The results obtained can be used to design plans and projects for forestry farms and increase the productivity of seedling cultivation in other countries with similar climatic conditions.

Materials and Methods

Production costs were estimated to compare the relevance of two approaches used for growing seedlings with open and closed root systems. Expenses required for planting material included the following items: seeds, staff salary, depreciation fees for the maintenance of buildings, facilities and equipment, electricity, water, and fuel for technological needs (Morkovina et al., 2017).

To determine the production cost of growing English oak seedlings with an open and closed root system, we used production charts. All operations were presented in the charts, providing the data on the consumption of fuel, water, materials, labour, machinery maintenance, equipment, and other production costs for each operation. The charts included the composition of tools, machines, and equipment, as well as the number and qualifications of workers to maintain them.

Cultivation of oak seedlings with an open root system included the following activities: basic ploughing of the soil; harrowing the soil in the spring after ploughing; cultivation of fallow with simultaneous harrowing; weed control; fertilising; treatment of acorns against diseases; winter storage of acorns in trenches; acorns sorting and drying; acorns sowing; annual pruning of seedling roots; watering of crops; spraying of oak seedlings with fungicides; manual weeding of crops; removing weed vegetation; cultivation and feeding of plants; seedlings extraction, sorting, accounting, and delivery to buyers.

Cultivation of oak seedlings with a closed root system included the following activities: acorns cleaning, processing and drying; acorns processing before sowing; substrate filling and feeding; mixing substrate and fertiliser with a mixer; filling cassettes with the nutrient substrate; planting acorns in cassettes; forming cassette stacks; taking cassette stacks to the greenhouse; watering crops; fertilising with mineral fertilisers; spraying oak seedlings with fungicides; selecting seedlings, accounting, and shipping to buyers.

Seedlings with closed root systems are grown in heated greenhouses with early spring planting of seeds in cassettes. Such cultivation method allows growing twice as many standard-sized seedlings (two rotations) in one season compared to the greenhouse without heating.

The total cost of growing seedlings with a closed root system was calculated for the following options:

(1) for growing CRS seedlings in greenhouses without heating in one rotation;
(2) for growing CRS seedlings in heated greenhouses in one rotation;
(3) for growing CRS seedlings in greenhouses in two rotations – the first with heating, the second without heating.

The formation of production charts for obtaining planting material of seedlings included the estimation of the following expenses:

(1) Costs for planting material production. The scope of work and composition of equipment, rates of production, labour costs were determined for the corresponding type of work. Interindustry standard production norms for forestry work in lowland conditions (Order of the Ministry of Health and Social Development of the Russian Federation of 26 April 2006 No. 317) were used in determining labour costs for most operations.
(2) Wage fund taking into account the type and scope of work required to create forest crops.
(3) Depreciation accruals for the maintenance of fixed assets used in the production process. The basic composition of equipment was determined in accordance with the technology of growing planting material.
(4) Costs for the purchase of raw materials, seeds, fertilisers, energy, water, and fuel. The cost of fuel, water, and electricity for technological needs was set, taking into account the current tariffs and rates.

To assess the technology of growing seedlings, the sales profitability indicator is applied, determined by the formula:

$$R = \frac{P}{C} \cdot 100\%, \quad (1)$$

Where P is the profit from seedlings sale and C is the cost of seedlings cultivation.

For comparative evaluation of growing seedlings with open and closed root systems, the investment analysis based on comparative estimates of discounted costs was employed.

The work was performed within the confines of the scientific school "Advances in Lumber Industry and Forestry".

Results and Discussion

The results of cost estimation for growing seedlings of English oak with open and closed root systems are presented in Table 1.

Analysis of production charts for growing seedlings of English oak showed that cultivation of CRS oak seedlings is technically a more expensive process compared to growing ORS seedlings. The costs of maintenance and use of machinery and equipment when growing CRS seedlings of oak in one rotation ranged from 209.4 to 5,583.6 thousand rubles per 1 hectare, in two rotations – 5,788.1 thousand rubles per 1 hectare, while growing seedlings with open root system required only 96.8 thousand rubles (Table 1).

A similar trend is observed for other cost items. As can be seen from Table 1, labour costs in growing CRS seedlings exceeded the costs of growing ORS seedlings by three and more times. It should be noted

Table 1: Comparative cost estimation for growing ORS and CRS seedlings of English oak

Indicator	*ORS Seedlings*	*VMS seedlings grown in a greenhouse*		
		Without heating	*With heating*	*In two rotations*
Maintenance of machinery and equipment per 1 hectare, rubles.	96,867.65	209,451.91	5 583 698.41	5 788 148.12
Wages per hectare, rubles.	272,835.59	877,821.70	877,821.70	1 748 240.42
Materials per 1 hectare, rubles.	132,618.00	1 860 224.00	1 860 224.00	3 720 448.00
Total costs of growing seedlings per 1 hectare, rubles.	502,321.24	2 947 497.61	8 321 744.11	11 256 836.54
Output of standard planting material, thousand pcs/ha	500	3,240	3,240	6,480
Unit production cost per 1 hectare, rubles.	1.00	0.91	2.57	1.74

that the cultivation of CRS seedlings requires highly specialised equipment, which predetermines the high need for qualified workers and the purchase of expensive equipment (Morkovina et al., 2017). The total production costs of growing CRS seedlings in one rotation exceed the costs of ORS seedlings cultivation by 5.8 times.

Total production costs of growing CRS seedlings in one rotation in greenhouses with heating are 16.5 times higher than that of ORS seedlings. Also, the full production costs of growing CRS seedlings in two rotations exceed that of ORS cultivation by 22.4 times.

When carrying out a comparative analysis of methods applied, it is important to consider the number of standard planting materials grown per unit of area. For seedlings with the open root system, the maximum number of standard seedlings per one hectare is 500 thousand plants. Cultivation of CRS seedlings allows increasing the yield of plants up to 3,240 thousand pieces in one rotation and 6,480 thousand pieces in two rotations.

Increasing the production allows reducing the cost of CRS seedlings to 2.57 rubles, making them competitive in price (Figure 3).

For seedlings of English oak grown with a closed root system and without heating, the production cost is 0.09 rubles lower than ORS oak seedlings. Such cost per seedling allows comparing both technologies and serves as proof of the cost competitiveness of the new technology in comparison with the traditional one. However, this competitive advantage is formed only under conditions of mass seedlings production. Increasing the number of rotations in the technology of growing CRS seedlings reduces the production costs to 1.74 rubles per seedling.

Taking into account non-production costs (commercial and administrative expenses), the total cost of growing one English oak seedling will be 1.8 rubles (Table 2).

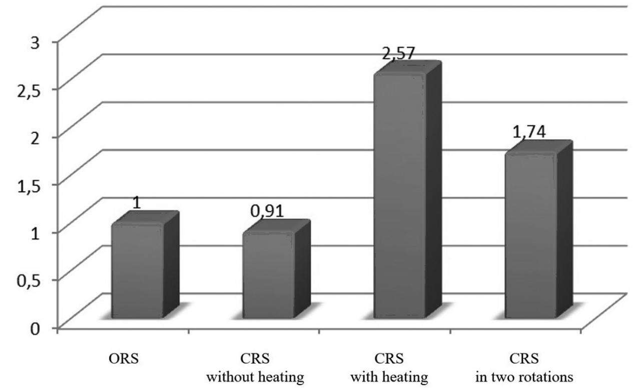

Figure 3: A comparative economic evaluation of total production costs for growing ORS and CRS seedlings.

With an increase in the number of oak seedling cultivation rotations, the price for CRS seedling is equal to the similar price of an oak seedling with ORS, amounting to 2.16 rubles.

Thus, the production cost of growing CRS seedlings is significantly influenced by the following factors: growing conditions (with and without heating) and the number of rotations allowed by the technology. The main factor that can reduce the production price of containerised seedlings is the scale of production, with the increase of which the price per seedling decreases due to savings on fixed costs.

The efficiency of growing seedlings using the new technology is usually evaluated by the level of production profitability. The calculations of the comparative profitability were based on assumptions that the price of CRS seedlings should not be higher than that of ORS seedlings to ensure the competitiveness of planting material (Table 3).

It has been found that the comparative profitability of growing ORS seedlings is higher when using the technology of cultivation without heating. The profitability of growing English oak seedlings with

Table 2: Total production costs and price of English oak seedlings with ORS and CRS

Indicator	*ORS seedlings*	*CRS seedlings in two rotations*
Production cost, rubles.	502 321.24	11 256 836.54
Sales and management expenses, rubles.	401 856.99	401 856.99
Output of standard planting material, thous. pcs./ha	500	6,480
Production cost of English oak seedlings, rubles.	1.00	1.74
Commercial and management costs, per unit of English oak seedlings, rubles.	0.80	0.06
The total cost of English oak seedlings, rubles.	1.80	1.80
Price per seedling, rubles.	2.16	2.16

Table 3: Indicators of the profitability level for growing oak seedlings with ORS or CRS

Indicator	*ORS seedlings*	*CRS seedlings*		
		Without heating	*With heating*	*Including two rotations*
Production cost of a seed- ling, rubles.	1.00	0.91	2.57	1.74
Total costs of seedlings, ru- bles.	1.80	1.03	2.69	1.80
The cultivation profitability level, fractions of units.	0.20	0.20	0.20	0.20
Profit per unit of production (seedlings), rubles.	0.36	0.21	0.54	0.36
Seedling price, rub.	2.16	1.24	3.23	2.16
Comparative profitability, fractions of units.	0.20	1.10	-0.20	0.20

Table 4: Indicators of project effectiveness in the cultivation of English oak seedlings with closed root system

Indicator	*Planning interval, year*					
	1	2	3	4	5	6
Cash flow from operating activities, rubles.	17,833	17,833	17,833	17,833	17,833	17,833
Total flow, rubles.	17,833	35,666	53,499	71,332	89,165	106,998
Investment activity, rubles.	80,696					
Cumulative flow balance, rubles.	-62,863	- 45,030	-27,197	-9,364	8,469	26,302
Discounted balance of total flow, rubles.	17,833	34,061	48,862	62,236	75,540	86,596
Net discounted income (NDI), rubles.	-62,863	-46,635	-31,834	- 18,460	-5,156	5,900
ROI with discount, years	5.46					
Cost Profitability Index, coeff.	1.07					

a closed root system in two rotations is equal to the profitability of growing ORS seedlings.

Investment analysis was applied to evaluate the possibility of implementing the investment project on the cultivation of English oak seedlings (Table 4).

Investment costs for growing CRS oak seedlings amount to 80,696.2 thousand rubles, including current production costs of 1,860.2 thousand rubles.

Sales profit from seedlings when reaching the design capacity amounts to 40,046.0 thousand rubles per year. The net discounted income of the project is 5,900 thousand rubles, which is considered profitable. The discounted ROI period was 5.5 years, indicating the effectiveness of the project.

Similar results were obtained by Miina and Saksa (2008), where the regeneration process of 5-year-old plots of artificial and natural regeneration of Scots pine (*Pinus sylvestris*) in Southern Finland was studied. The simulation results showed that artificial cultivation (including CRS seedlings) was more effective in terms of seedling adaptability and growing costs than ORS planting and natural regeneration. Also in the work by Jäärats et al. (2016), it was shown that the growth and survival of *P. sylvestris* and *P. abies* conifers were affected by the type of planting material for eight years after planting in hemiboreal Estonia. Experimental results showed that reforestation with container seedlings is the preferred option because of easy transportation and better stress tolerance to weather changes. Similar conclusions were drawn in the works of Löf et al. (2019) and Pemán et al. (2017) when studying the efficiency of growing oak seedlings when natural reforestation is impossible.

Conclusions

Successful reforestation in Russia is determined by the availability of quality planting material that ensures a high survival rate and safety of seedlings. Despite the great potential of growing CRS seedlings of tree species, economic issues concerning the effectiveness of its application in practice remain underdeveloped. The results of the study show the competitive advantages of applying new technology in terms of profitability of production and price of oak seedlings. Minimum cultivation costs have CRS seedlings grown without heating in greenhouses in one rotation for mass production. It has been established that increasing the number of rotations in growing CRS seedlings reduces the production cost and makes the seedlings of English oak grown with such technology competitive in price with ORS seedlings. It has been shown that the use of CRS materials for planting forest crops is cost-effective compared to conventional planting material.

When arranging the production of CRS seedlings, the discounted ROI period is 5.5 years. Effective implementation of regeneration processes in forestry of the Russian Federation, taking into account quite a significant ROI period, requires state support for the transition of forest nurseries to innovative technologies of growing forest planting material.

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Conflict of Interests

The authors declare that they have no conflict of interests.

Data Availability

Data will be available on request.

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