Economic assessment of application of new reforestation technologies in conditions of climate change in the forest-steppe zone of Russia

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Abstract. The development and application of new reforestation technologies remain relevant due to climate change. The main technology of forest sowing in Russia does not provide effective reforestation. Innovative technologies of reforestation based on seedlings with a closed root system make it possible to increase the livelihood of plants and accelerate reforestation processes. Using the method of determining costs, a comparative economic analysis of the technologies for growing oak seedlings with an open and closed root system in the forest-steppe regions of Russia was carried out. It was found that the technology of growing seedlings with a closed root system is less labor-consuming and provides a high level of income for investments. The innovative technology of growing seedlings with a closed root system in greenhouses is more competitive and its use allows to generate income from one hectare of area 50 times more than when growing seedlings in forest nurseries by increasing the number of seedling rotation. A comparative economic assessment of two oak seedling projects under forest-steppe conditions suggests the feasibility of moving to innovative reforestation technologies. In the current climate change conditions, a serious correction of approaches to reforestation in the forest-steppe zones of Russia is necessary.

1. Introduction
The global community recognizes that climate change cannot be avoided and forest ecosystems alone cannot adapt to projected changes [1]. The impacts of climate change are manifested at the global, regional, subregional and national levels. Global climate change creates a situation for the Russian Federation (taking into account the size of its territory, geographical location, the exceptional diversity of climatic conditions, the structure of the economy, demographic problems and geopolitical interests), which implies the need for advance formation of methods and technological solutions that contribute to adaptation [2].

In the zone of special risk are forest ecosystems of forest-steppe regions where there is already an increase in the aridity of territories. The need to switch to new technologies for the cultivation of plantations in the forest-steppe regions of Russia is confirmed by the growing demand for woody plants resistant to adverse climatic factors. Moreover, forest ecosystems are characterized by the
delayed effects of innovation diffusion, as forest management usually takes several decades. The main method of reforestation in Russia is planting seedlings with an open root system [3]. Reforestation of 90% of forest area is carried out by this method. Much of the published work on the application of new technologies relates to adaptation of forests to climate change, while managers need more detailed assessments and recommendations on reforestation in climate change. The researchers deal with the reforestation issues randomly. For example, some reviews are devoted exclusively to the topic of substrates and containers for growing forest seedlings, others relate to the quality of the range of seedlings, the timing of planting and soil moisture or technical solutions for planting forest seedlings [4-10]. In particular, Wightman K, Shear T, Goldfarb B investigated the growth of seedlings of three economically important and environmentally friendly local hardwoods, Cordia alliodora (Boraginaceae), Hyeronima alchorneoides (Euphorbiaceae) and Calophyllum brasiliense. They were grown in different types of containers using different substrates. Scientists came to the conclusion that the species in the nursery primarily reacted to the type of substrate [4]. Thiffault N notes that intensive plantation management requires seedlings to have characteristics specifically designed for their growth, but the success of the plantation requires both the correct type of planting material and appropriate forestry [5]. Holl K D and Aide T M recommend taking into account the complex of environmental and human factors before choosing an approach to reforestation. First, it is necessary to consider what the probable outcome of a natural restoration approach will be based on the natural ecosystem stability, history of land use and the matrix of the surrounding landscape. It is also necessary to define the specific objectives of the project and assess the resources available. Conducting this analysis prior to choosing reforestation approaches should lead to more efficient use of reforestation resources and maximize the success of reforestation efforts [6]. Grossnickle S C and MacDonald J E investigate how seedling quality is used in reforestation programs and the parameters that are measured to determine quality [7]. Laudon H, Sponseller R, Lucas R, Futter M, Egnel G, Bishop K, Agren A, Ring E, Högborg P believe that nutrient addition, faster growing tree varieties, more intensive harvesting practices and changing climate – all of this could increase Sweden's forest production, thereby mitigating the effects of climate change by carbon sequestration and replacing fossil fuels. Scientists are studying and debating some of the most pressing issues related to how increased forest biomass production in Sweden can affect soils and surface waters, and how modern forestry goals can be achieved while minimizing the loss of other ecosystem services [8]. Promis A and Allen R believe that seedlings of co-occurring species differ in their response to resource availability. This has implications for forest conservation and management. Different shade tolerance affects the productivity of seedlings in the mixed forests of Nothofagus betuloides - Nothofagus pumilio in Patagonia. However, these species also differ in the nutrient requirements of the soil. In order to determine the effect of light and soil nutrient resources on small seedlings, scientists studied the response to an experimental reduction in competition between the roots of canopy trees by digging out the roots and limiting soil nutrient depletion through the addition of fertilizers. To understand the effect of light, these procedures were carried out in small intervals between the canopy and nearby under an undisturbed canopy at a lower illumination level. The results support the notion that soil nutrient resources, as well as more widely studied light sources, are important for seedlings of Nothofagus species growing in infertile soils [9]. Ersson B, Laine T, Mechanized T found that currently mechanized tree planting in Sweden and Finland has more similarities than differences. Due to similar problems, mechanized planting in both countries can increase profitability through training of the foresters involved, flexible information systems, efficient seedling logistics and continuous technical development of planting machines [10].

At the same time, a comparative assessment of reforestation technologies in the context of climate change for the forest-steppe zone is not presented. These characteristics emphasize the need to study and conduct a comparative assessment (including economic) of new reforestation technologies for the adaptation of forest ecosystems to climate change. In this regard, the purpose of our study was the economic assessment of the application of new technologies for reforestation in the context of climate change in the forest-steppe zone of Russia.
2. Methodology
The study used a comparative method of estimating the costs of reforestation of a forest plot using two technologies. The first technology was based on the use in reforestation of seedlings with an open root system prevailing in the forestry of Russia. The second technology, the new one, was based on the use of closed root system in reforestation of seedlings. The cost was calculated using the technology of growing common oak seedlings. In order to determine the cost of growing oak seedlings with an open root system in the forest nursery, the following types of work were taken into account: the main soil plowing; soil harrowing after plowing; steam cultivation with simultaneous harrowing; weed control; fertilization; acorns treatment for diseases; winter storage of acorns in trenches; acorns sorting and drying; acorns sowing; annual cutting of the roots of seedlings; watering crops; spraying oak seedlings with fungicides; manual weeding of crops, removal of weeds; cultivation and feeding of plants; digging up seedlings, sorting, accounting and shipping to buyers.

In order to determine the cost of growing seedlings with a closed root system in the greenhouse, the following types of work were taken into account: cleaning, processing and drying acorns; substrate preparation, and fertilizer application; filling the cassettes with substrate; planting acorns in cassettes; transportation and placement of cassettes with seeds in the greenhouse; watering crops; mineral fertilizer feeding; spraying oak seedlings with fungicides; seedling sampling, sorting, accounting and packing [11].

The cost of growing common oak seedlings included the following types of production costs:
- employees’ wages
- costs of maintenance of buildings, structures and equipment necessary for seedling cultivation;
- costs of seed purchase;
- costs of energy, water and gasoline consumed in the process [12].

All calculations were made on one hectare (ha) of effective area. When growing seedlings with an open root system, the number of plants per ha of effective area was taken equal to 500,000 units. When growing seedlings with a closed root system, the number of plants per ha of effective area was taken equal to 3,240 units.

In each technology, we identified separate operations for which the consumption of the consumed resource was established. For a comparative assessment of the technology of growing seedlings, a profitability index of sales is used, determined by the formula:

\[ PI = \frac{PV}{IC} \]  

Where:
- \( PI \) – profitability index;
- \( PV \) – the total net cash proceeds from sales of seedlings over “k” years;
- \( IC \) – the amount of initial investment in seedling cultivation.

The calculation of the return on investment index in seedling cultivation using the new technology was made on the basis of the net present effect. In the course of the research, both general scientific methods were used: analysis and synthesis, generalization, analogy, as well as specific ones: system analysis, formalization, graphic, tabular, comparative methods.

3. Results and discussion
In recent years, reforestation has been increasing in the Russian Federation, which is associated with an increase in logging volumes and growing demand for products from environmentally friendly materials. The second factor is forest fires, the frequency and magnitude of which are increasing due to climate change. Over ten years, the reforestation area in the regions of Russia increased by 36.1%, amounting to 1,126.5 ha (figure 1). Reforestation in Russia is carried out in three ways – seedlings planting, seeds sowing or by naturally growing forest areas.
The third factor affecting the volume of reforestation is the livelihood of seedlings, which remains not high, in a number of regions does not exceed 50%, and significantly correlates with the method of planting. This fact determines the need to repeat the seedlings planting and significantly increases the cost of reforestation. The proportion of forest areas allotted for planting seedlings is 15% of the total area requiring reforestation in Russia. It is known that innovative technologies for reforestation based on seedlings with a closed root system allow to increase the livelihood of plants and accelerate reforestation processes. Although the directions of the efforts of the government to introduce innovative reforestation technologies are objectively still under development, it is already possible to draw the first conclusions about the effectiveness for practice. The proportion of seedlings grown using new technologies is only 5% of the total number of seedlings grown for reforestation. In this regard, economic calculations aimed at justifying the use of new reforestation technologies are primarily necessary. In the course of the research, economic analysis of technologies of growing oak seedlings with an open and closed root system was carried out, the results of which are given in table 1.

Table 1. Comparative characteristics of seedlings cultivation costs with open and closed root system.

| Indicator                                      | Open root seedlings | Closed root seedlings |
|------------------------------------------------|---------------------|-----------------------|
| Maintenance of machinery and equipment, USD    | 1,278.65            | 74,798.47             |
| Wages, USD                                     | 3,601.43            | 11,587.25             |
| Seeds, water, fertilizers, electricity, fuel, USD | 1,750.56            | 24,554.96             |
| Total costs, USD                               | 6,630.64            | 110,940.67            |
| Production cost per seedling, USD, incl.       | 0.013               | 0.034                 |
| maintenance of machinery and equipment         | 0.0025              | 0.023                 |
| salary                                         | 0.0073              | 0.0036                |
| supplies                                       | 0.0034              | 0.0075                |

aHere and further in the tables the data on the transfer of currency from the Russian ruble (RUB) to the US dollar (USD) is relevant for 29.03.2021.

Growing seedlings with an open root system is a less costly process. The cost of growing one seedling is 0.0034 USD, which is 2 times lower than the cost of a seedling grown with a closed root system. The cost of maintaining equipment with the technology of growing seedlings with a closed root system is significantly higher than with the traditional method of growing seedlings. At the same time, innovative technology is more technological, which leads to halving the labor costs compared to traditional technology. In the spending pattern of the cultivation of oak seedlings using traditional technology, costs of labour are the largest, while in the spending pattern of the cultivation of oak seedlings using innovative technology, the maintenance of machinery and equipment costs are the largest.
The second place in the spending pattern for growing seedlings both with an open and closed root system, is allocated to material costs – from 22 to 26%. Investment costs in traditional technologies of growing oak seedlings with an open root system are relatively low and amount to 33,000 USD. At this level of investments, the cost of growing 500,000 seedlings per ha of land is 6,630 USD/ha. The expected revenues from sales of oak seedlings and discounted cash flows are shown in table 2.

**Table 2.** Income and cost of growing oak seedlings using traditional technology.

| Indicator | Project implementation interval, year |
|-----------|-------------------------------------|
|           | the first  | the second | the third | the fourth | the fifth | the sixth |
| Sales revenue, USD | 14,520 | 15,680 | 16,320 | 16,960 | 17,650 | 18,300 |
| The full cost of growing seedlings, USD | 6,630 | 7,130 | 7,420 | 7,710 | 8,030 | 8,340 |
| Profit, USD | 7,920 | 8,550 | 8,900 | 9,250 | 9,620 | 9,950 |
| Income tax, USD | 1,580 | 1,710 | 1,780 | 1,850 | 1,920 | 1,990 |
| Net profit, thousand USD | 6,340 | 6,840 | 7,120 | 7,400 | 7,700 | 7,960 |
| Discounted cash flow by operating activity, USD (PV) | 6,340 | 6,340 | 6,350 | 6,380 | 6,360 | 6,320 |
| Investment costs, USD (IС) | 33,000 | – | – | – | – | – |
| Net discounted cash flow for operating activities, USD | -26,660 | -20,330 | -13,970 | -7,590 | -1,230 | 5,090 |

Traditional technology, despite the low level of investment costs, provides cover expenses with a net discounted income of 5,000.09 USD. The payback period is the sixth year of the project implementation. In order to compare the traditional and innovative technology of growing oak seedlings in forest-steppe conditions, the efficiency of the project of growing oak seedlings with a closed root system is calculated in table 3.

**Table 3.** Income and cost of growing oak seedlings on innovative technology.

| Indicator | Project implementation interval, year |
|-----------|-------------------------------------|
|           | the first  | the second | the third | the fourth | the fifth | the sixth |
| Sales revenue, USD | 538,880 | 581,970 | 606,160 | 630,410 | 655,620 | 681,850 |
| Full cost of growing seedlings, USD | 153,960 | 166,520 | 173,180 | 180,110 | 187,320 | 194,810 |
| Profit, thousand USD | 384,910 | 415,460 | 432,970 | 450,290 | 468,300 | 487,040 |
| Income tax, USD | 76,980 | 83,090 | 86,590 | 90,060 | 93,660 | 97,410 |
| Net profit, USD | 307,930 | 332,370 | 346,380 | 360,230 | 374,640 | 389,630 |
| Discounted cash flow by operating activity, USD (PV) | 307,930 | 307,750 | 309,270 | 310,550 | 309,620 | 309,230 |
| Investment costs, USD | 1,065.19 | – | – | – | – | – |
| Net discounted de-gentle flow by operating activity, USD | -757,260 | -449,510 | -140,240 | 170,300 | 479,920 | 789,150 |

Growing oak seedlings in greenhouses of the forest-steppe zone of Russia is possible in two rotations. At the same time, the annual volume of seedlings per ha can be increased to 6,480 pieces. The average sale price of oak seedlings with a closed root system is 0.083 USD. Then the sales volume of oak seedlings for the estimated period is 538,880 USD per ha of land. Taking into account the described above methodological approach, the total cost of growing oak seedlings with a closed root system of 153,960 USD was established per ha. Investment in the technology of seedling
cultivation with a closed root system of 1,065.19 USD. Discounted income for the project of growing oak seedlings with a closed root system for six years will be 789,150 USD, and the payback period of the project is 4 years. A comparative economic assessment of two oak seedling projects under forest-steppe conditions suggests the feasibility of switching to innovative reforestation technologies. Despite the high cost and costs of growing seedlings with a closed root system, through economies of scale and improved seedlings growth, its application in practice can improve the reforestation situation. The innovative technology of growing seedlings with a closed root system in greenhouses is more competitive and its use allows to generate income from one ha of area 50 times more than when growing seedlings in forest nurseries.

4. Conclusion
In the current climate change conditions, there has been a serious correction of approaches to reforestation in the forest-steppe zones of Russia. The concentration of efforts on the creation of technologies that ensure the livelihood of seedlings and rapid growth has led to the emergence of innovative technology for growing seedlings with a closed root system. The switch to innovative reforestation technologies means not only an increase in technical effectiveness of processes and reduction of their labor intensity, but also the need for significant investments. The full cost of growing seedlings is a significant constraint to the use of innovative technologies in reforestation. The cost of oak seedlings grown with a closed root system is 2.5 times higher than the cost of seedlings with an open root system. By increasing the number of rotation of seedling cultivation and the use of automated technical solutions, it is possible to increase the competitive performance of innovative technology. The discounted payback period of the project for growing oak seedlings using innovative technology is 4 years. Despite significant investments in innovative technologies for growing seedlings with a closed root system, we can expect a significant improvement in economic indicators: growth in labor productivity and profit, which, given the growing aridity of the climate of the forest-steppe regions of Russia, is an additional bonus to the use of new campaigns in reforestation.

Our results provide international readers with detailed and comprehensive figures and characteristics of technologies for growing planting material with open and closed root systems.

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