Analysis of promising methods for felling for forest care by multi-operation systems of machines

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Abstract. One of the leading places in the complex of measures to increase the productivity of forests and the rational use of wood resources is occupied by thinning for forest care. Timely and justified thinning for forest maintenance allows not only increasing the productivity and sustainability of forests, increasing the size of forest use, but also creating prerequisites for the effective implementation of environmental protection and climate control functions by forests. Growing highly productive stands of optimal composition requires regular forest maintenance. In the Republic of Belarus, forest thinning is carried out by various multi-operational systems of machines and methods, each of which has its own characteristics and efficiency depending on the conditions of their operation. This article analyzes the effectiveness of thinning for forest care in the conditions of forestry institutions of the Republic of Belarus using multi-operational systems of machines. The most important goals for the development of the country's forestry are noted, among which are the provision of the formation of highly productive and sustainable forests, as well as increasing the resource potential of forests to meet the needs of the environment and society.

1 Introduction

One of the most important goals for the development of the country's forestry is to ensure the formation of highly productive and sustainable forests, increasing the resource potential of forests to meet the needs of the environment and society. These goals are reflected in state programs and strategies (the State Program "Belarusian Forest" until 2025, the strategic plan for the development of forestry until 2030, etc.) [1, 2].

To achieve the goals set, one of the most important areas of intensive forestry is high-quality and timely thinning, where machine complexes with a wide range of technical characteristics of technological equipment and base chassis are increasingly used [3, 4]. The aim of the study is to study the methods and techniques of forest thinning in the Republic of Belarus.

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2 Results and discussion

Forest maintenance felling is one of the most important forest management activities aimed at growing economically valuable, highly productive, high-quality plantations and improving other useful properties of the forest, increasing the volume of forest use in accordance with the technological requirements established by STB 1361-2002 "Sustainable forest management and forest use. Intermediate fellings. Requirements for technologies" [5, 6]. They consist in periodically cutting down unwanted trees and shrubs from plantations to create favorable growth conditions for the best trees of the main species and serve as a source of wood and other raw materials.

Over time, forest plantations change. This is due to the appearance of diseased and pest-damaged tree trunks, dead wood, and an increase in the density of forests. As a rule, the types of thinning depend on the age of the forest (at the time of implementation). The Table 1 shows the types of thinning according to the Rules for logging in the Republic of Belarus [7]. Currently, in the Republic of Belarus, both gasoline-powered saws and "harvester-forwarder" machine systems are used to carry out forest thinning [8].

Table 1. Types of thinning.

Type of thinning	**Plantation age, years**			
	coniferous	**deciduous**		
		oak, ash, maple seed and mixed origin	**birch, black alder, linden, hornbeam**	**poplar, aspen, gray alder**
Lightening	1–10	1–10	1–10	to 5
Cleaning	11–20	11–20	11–20	6–10
Thinning	21–40	21–40	21–30	11–20
Clear felling	41 and up	41 and up	31 and up	21 and up

Comparison of machine systems based on gasoline-powered saws and harvesters allows us to conclude that one of the main reasons for the massive transition to mechanized thinning is the lack of labor. At the moment, in many regions it is problematic to recruit a team of fellers, since the number of people working in rural areas has decreased markedly in recent years. In this regard, the implementation of technologies for thinning the forest with the use of multi-operation harvesting machines such as a harvester and a forwarder has become more rational, since this system of machines provides high labor productivity while complying with forestry and environmental requirements. The features of forest care felling using these machines, in contrast to the use of gasoline-powered saws, are: mechanization of logging operations, cutting down trees without preliminary selection and marking (taking into account the experience and qualifications of the harvester operator), improving working conditions, increasing the degree of labor safety and reduction of injuries, reduction of timber harvesting time, etc. [9, 10].

Small-sized logging machines from Vimek, Rottne, SampoRosenlew, Amkodor, Usewood, Logbullet, PonsseFox, etc. are used in thinning in the Republic of Belarus.

The organization of thinning for forest care includes the breakdown of the cutting area into technological elements, including the arrangement of technological corridors (portages) and loading areas. Depending on the type of logging, the machines used and the characteristics of the forest fund, methods with and without portages can be used.

Using the method of developing logging sites with the laying of technological corridors, it is necessary to cut down a number of trees, including the best and main species. It is used when it is necessary to ensure the unhindered movement of forest machines, the width of

which is 2 m or more. In this case, the technological corridor turns out to be 3.5–4 m wide, i.e. it is necessary to cut it down with a width equal to a quarter clearing only in order to haul (haul) the harvested assortments to their storage sites. Under these conditions, such machines as MLKh-46, Amkodor 2531, 2541 are used for thinning, less often for thinning. In some cases, when carrying out such cuttings using machines based on Vimek, when hauling timber, due to the large turning radius of a loaded forwarder, it is also necessary to cut through a technological corridor [11].

The method of developing logging sites without laying technological corridors is based on the use of Vimek, Usewood, Logbullet machines. At the same time, the machines move curvilinearly between the trees, the technological corridor is not cut through, but the trajectory of their movement is outlined. However, it must be taken into account that this trajectory must allow a forwarder with timber to pass, since where a harvester can pass, it is not always possible for a forwarder to pass.

Based on the cutting method and the selected machines, the laying of corridors can be done both in a straight line and in a curvilinear way. The straight-line method simplifies the breakdown of the cutting area into technological elements and skidding of harvested wood, the curvilinear method allows machines to bypass single trees of the main and economically valuable species and other obstacles, and also reduces the wind load on the plantation, however, it reduces the distance between the technological parking lots of the machine due to the need to ensure accessibility and limiting damage to trees remaining in the cutting area [12].

When carrying out the combined method, systems of machines "harvester-forwarder" and gasoline-powered saws are used. The main volume of timber harvesting is mastered by a harvester, and in hard-to-reach areas of the cutting area, trees are further processed with a gasoline-powered saw. The use of the combined method in thinnings ensures maximum productivity and a large yield of industrial wood, and thanks to mechanized equipment, costs are reduced and labor productivity is increased. A significant difference of this method is the use of gasoline-powered saws in a system with a harvester and a forwarder. This makes it possible to reduce the degree of damage to the trees of the main species, which are left for growing, by cutting down unwanted trees.

The method of harvesting woody biomass [13] with the use of a Vimek 610 SE BioCombi harvester, which can work in the mode of harvesting small-sized wood at clearings without delimbing, and transport trees to storage sites, is also used. Its use is more rational for clearing areas from unwanted small-sized tree and shrub vegetation in order to harvest fuel biomass for energy purposes. The use of combined machines that allow you to perform harvesting and skidding operations makes it possible to increase productivity. As a rule, this method is used in the case where there is no commercial timber [14].

The Vimek 404 DUO Bio harvester can also be used to develop this method. The method of operation does not differ from the classic harvester-forwarder machine system, except for the combination in one machine of a full-fledged harvester capable of working in forwarder mode, and not vice versa.

The harvesting and removal of wood with subsequent processing into fuel chips also finds application in the Republic of Belarus [15, 16]. When carrying out early thinning, significant amounts of biomass are formed in the form of small-sized wood. With a small volume of the whip, all harvested wood can be assigned for processing into fuel chips. The method is based on the fact that after thinning, the harvested wood is divided into industrial and firewood, where firewood is transported for further processing to the upper or intermediate warehouse. The advantage of this method is the rational use of wood raw materials.

The harvester-forwarder machine system is used in all types of thinning. In their classical use, a forwarder moves after the harvester, collecting harvested assortments. However, there is a technology according to which the forwarder does not move along each harvester track,

but through one. At the same time, the harvester stacks harvested assortments at the maximum reach of the manipulator, closer to the border of the apiary, where the movement of the forwarder is excluded. But this condition is met only if the manipulator can be reached both as a harvester for possible stacking and as a forwarder for subsequent harvesting of timber. Thus, the work of the forwarder is simplified, since the boundaries of apiaries are maintained, but in addition to this, thinning is increased. When using this technology, it is worth focusing on a forwarder, since its advantage is a large turning radius of the manipulator reach, high carrying capacity, and high maneuverability. In this regard, the forwarder path is reduced by about half, or even three times, while the time to fill the loading platform is reduced, where, as a result, the productivity of the machine increases. With this technology, it is not necessary to move the machines one after another and it does not matter how the felling, bucking and delimbing will be done - with a hand tool or a harvester. The main thing is that the harvested assortments should be stacked in a pack, and also be within the visibility and reach of the forwarder manipulator along the way of its movement. If you take a harvester, then when harvesting timber, the operator lays them next to him along the passing path, where the forwarder will pass after him. As a result, no corridors are laid and a uniformly thinned forest remains. The choice of a forwarder affects the technological process, as well as the silvicultural requirements of thinning [17, 18, 19].

In connection with the large variety of dimensional, qualitative and biometric indicators of the forest stand, it is important to make a reasonable choice of technological equipment and parameters of forest machines. First of all, the main parameters include the width and weight of the harvester and forwarder [20, 21], since the minimum width of the machines avoids damage to the best trees of the main species. As practice shows, for thinning it is better to use small-sized machines with a manipulator boom reach of up to 6 m. As for weight, it is important to use light machines to prevent damage to root systems and soils. However, when thinning and clearing, the dimensions of the machines are taken into account so that they can work under the forest canopy without laying corridors. For a better yield of quality wood, both machines must be interconnected and coordinated with each other in terms of technical and technological parameters. As a result, the technology of work on thinning forests should be based on two main criteria: silvicultural and economic ones. The silvicultural criterion reduces the risk of damage to the best trees of the main species, and the economic criterion leads to a reduction in operating costs for felling.

Currently, one of the indicators characterizing the work of Vimek harvesters [22] in thinning in forestry enterprises is the volume of harvested timber per month, in accordance with which the operator's wages are paid. However, taking into account the purpose of thinning, it is advisable to use as such an indicator not the volume of harvested wood, but the area covered by thinning [23-25]. This will improve the quality of thinnings, not excluding control over the operation of machine systems.

3 Conclusion

The analysis of methods and ways of carrying out thinning for forest care was carried out, which showed that in the Republic of Belarus both systems of machines based on a harvester and gasoline-powered saws are used. At the same time, one of the most important reasons for the introduction of multi-operational logging machines is the lack of labor force for the timely comprehensive implementation of thinning.

A comparative analysis of the use of machine systems based on gasoline-powered saws and harvesters showed that the use of machine systems ensures high-quality logging in accordance with STB 1361-2002, while increasing labor safety, improving working conditions, reducing logging time, and increasing the efficiency of organizing forest management and forestry work.

Based on the study of various methods of carrying out thinning for forest care by the system of harvester-forwarder machines, the following of them are proposed for use in the conditions of the Republic of Belarus:

- with rectilinear laying of technological corridors and breakdown into apiaries;
- with laying of curvilinear technological corridors;
- without laying technological corridors, with an outline of the trajectory of the harvester and forwarder under the forest canopy;
- combined method with the use of harvester-forwarder machines and gasoline-powered saws in a complex;
- woody biomass harvesting method using a Vimek 610 SE BioCombi harvester;
- classical method with or without laying of technological corridors using the Vimek 404 DUO Bio harvester.

Machine systems recommended for carrying out the above methods have been installed. In passing cuttings, less often in thinning, machines PonsseFox, MLH-46, Amkodor 2531, 2541 can be used. In thinning with the laying of technological corridors, machines based on MLH-46, Amkodor 2531 and less often Vimek 404 SE are used to a greater extent. Without laying technological corridors, Vimek machines can be used for thinning and passing cuttings, and Usewood, Logbullet for clearing and thinning.

Based on the research, it is possible to carry out a reasonable choice of machine systems for the appropriate methods and techniques for thinning, which will ensure compliance with forestry requirements, as well as the requirements of the STB 1361-2002 standard, etc.

After the analysis of thinning production in forestry enterprises, as recommendations, it was proposed to use, instead of the normative indicator of the volume of felling, the indicator of the area covered by felling to assess the rationing of labor and wages.

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