Review of designs of cultivators for agricultural care of forest crops

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Abstract. The article analyzes the designs of various types of cultivators, which are used to remove unwanted herbaceous and tree-shrub vegetation. Cultivators with disk, rotary, milling and tine working bodies are considered. It is shown that quite a lot of material resources are spent on carrying out agro technical care for valuable forest crops. It is noted that the mechanical method of soil care in the aisles and rows of forest crops has become widespread, despite the high costs. It was found that the rotary cultivators KRL-1M and KBL-1 during their movement cover seedlings up to 15 cm high with soil, and in plants 40-50 cm high and higher, when saddling a row, the apical bud breaks off, the bark is peeled off, side branches break. Damage to forest crops is about 8%. Damage and destruction of cultivated plants by the KRT-3 cultivator is 30%, and by the KFL-1.4 cultivator - 43%. Cultivator KRT-3 has low reliability. When meeting with stumps, the racks of the working bodies and wheels are deformed, and the paws are often broken. The milling cultivator KFL-1.4 also has low operational reliability.

1 Introduction

Use The forestry of the country is distinguished by a variety of conditions on which the methods and technological methods of the work performed depend. Every year in our country, sowing and planting forests are carried out on an area of more than 1 million hectares, of which a significant part falls on coniferous crops, created, as a rule, by planting.

A lot of resources are spent on caring for crops, since care directly in the rows and protective zones is not fully mechanized due to the extreme complexity of this operation, which requires exceptionally high accuracy of the movement of the cultivator's working bodies, and this operation, in in most cases, they are performed manually [Bartenev et al., 2010, 2013, 2015; Goncharov et al., 2016; Zhdanov et al., 2011; Posmetiev et al., 2011; Svechnikov, 2013].

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Scotch pine, as one of the tree species, has an exceptionally valuable biological feature and grows in a wide variety of types of forest conditions. In our country, pine accounts for an average of 70% of the forestry fund.

Agrotechnics for growing pine crops includes a complex of individual agro technical practices, among which crop care occupies a very important place.

Many researchers note that in uncultivated areas before planting forest crops at the end of the first growing season, the projective cover with cereals is 36%, in the second year 70-75%, in the third year - 80-90%. It is noted that in areas without soil preparation, the process of transformation from weedy to rhizomatous or reed stage proceeds mainly in the second year, and in areas where soil preparation was carried out, only in the third year.

In the special literature, soil care in pine crops is recommended for 4-5 years: in the first year - 4, in the second - 3, in the third - 2 and in the fourth - 1 care. In terms of time, the first departure is scheduled for the end of April - the beginning of May, the second - for the end of May, and then in June or July and in September [Vinokurov et al., 2021; Grigoriev et al., 2020, 2022; Mashtakov, 2018; Suchkov et al., 2020; Tarasenko et al., 2015; Balabanov et al., 2021].

Currently, mainly mechanical and chemical methods of caring for forest crops are used. The mechanical method of soil care in row-spacings, protective zones and rows of forest crops has become widespread. It ensures the destruction of weeds in the growth zone of seedlings, contributes to the accumulation and conservation of moisture [Afonichev et al., 2015; Barteniev et al., 2011; Bobrinev et al., 2010; Drozdov et al., 2005; Zhdanov et al., 2015; Kovylina et al., 2019; Kulik et al., 2018; Latysheva, 2014].

The goal is to analyze the designs of various types of cultivators that are used for tillage and removal of undergrowth.

2 Materials and methods

When writing the article, various databases and printed publications were used. The search for information was carried out using electronic resources (KiberLeninka, eLIBRARY, Google Academy), the Yandex search engine with queries: (forest tillage implements) OR (forest cultivator) AND (milling cultivator). Textbooks and dissertations from the scientific library of VGLTU were used as printed publications.

Some designs of tillage machines were selected and a statistical analysis of the degree of their similarity and difference in terms of parameters (working speed, working width, tillage depth, mass) was carried out. For this, a hierarchical similarity diagram was used, which determines the differences in parameters using the measure of the square of the Euclidean distance. The StatSoft Statistica 10 program was used for data processing.

3 Results and Discussion

The results of a comparative analysis of the parameters of cultivators are given in table 1 and in figure 1.

Analyzing the hierarchical diagram (Figure 1), we can say that it is divided into eight clusters. The first cluster includes two cultivators (KRL-1A, KBL-1A), the second cluster - one cultivator (KF-1.5), the third - also one cultivator (KDS-1.8), the fourth - two cultivators (KF-1.4, KLB-1.7), in the fifth - one (KLP-2.5), in the sixth - two (KL-2.6, KRT-3), in the seventh - one (RA-1), in the eighth - also one cultivator (KUN-4). The first cluster included cultivators that have a high working speed, an average working depth, a small working width and weight. The second cluster includes a cultivator, which has a high working speed, an average working width and weight, and a small working depth. The
A cultivator included in the third cluster has a large mass, an average working depth and working width, and a low working speed. The fourth cluster contains cultivators that have an average working width, working depth and weight, and a low working speed. In the fifth - a cultivator, which has a large working width, average working speed, working depth and weight. In the sixth cluster are cultivators who have all the high scores. In the seventh cluster there is a cultivator with a large working depth, an average working speed, a small working width and weight. In the eighth - a cultivator, which has a large working width and weight, an average depth of processing, low working speed.

![Fig. 1. Hierarchical diagram of similarities and differences of cultivators by design parameters.](image)

### Table 1. Comparative analysis of design parameters of cultivators.

<table>
<thead>
<tr>
<th>Mechanization tool</th>
<th>Operating speed, km/h</th>
<th>Width capture, m</th>
<th>Depth of processing, cm</th>
<th>Weight, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>KRL-1A</td>
<td>8-10</td>
<td>0.8</td>
<td>10</td>
<td>245</td>
</tr>
<tr>
<td>KDS-1.8</td>
<td>3-3.5</td>
<td>1.8</td>
<td>6-12</td>
<td>980</td>
</tr>
<tr>
<td>KLP-2.5</td>
<td>4-6</td>
<td>2.5</td>
<td>6-15</td>
<td>750</td>
</tr>
<tr>
<td>KUN-4</td>
<td>3-3.5</td>
<td>2.9-4.3</td>
<td>in rows 6-8 between the rows 8-15</td>
<td>1420</td>
</tr>
<tr>
<td>KL-2.6</td>
<td>8</td>
<td>2.55</td>
<td>12-16</td>
<td>613</td>
</tr>
<tr>
<td>KBL-1.1</td>
<td>6-9</td>
<td>0.6-0.7</td>
<td>3-8</td>
<td>300</td>
</tr>
<tr>
<td>CFL-1.4</td>
<td>3-3.5</td>
<td>1.4</td>
<td>6-12</td>
<td>500</td>
</tr>
<tr>
<td>CLB-1.7</td>
<td>3</td>
<td>1.7</td>
<td>6-12</td>
<td>570</td>
</tr>
<tr>
<td>KRT-3</td>
<td>5.2-8.3</td>
<td>1.5-2.5</td>
<td>16</td>
<td>950</td>
</tr>
<tr>
<td>RA-1</td>
<td>5</td>
<td>0.7</td>
<td>15</td>
<td>340</td>
</tr>
<tr>
<td>KF-1.5</td>
<td>6-9</td>
<td>1.5</td>
<td>2-8</td>
<td>820</td>
</tr>
</tbody>
</table>

By purpose, forest cultivators can be divided into those used in clearings, in field-protective afforestation, on slopes, on terraces and in nurseries. According to the type of working bodies in forestry, they use disk, with clawed working bodies, rotary and milling.

To care for forest plantations in rows, cultivators KRL-1M, KRSSH-2.8 and PRO devices are widely used. Currently, cultivators KRL-1A (modernized) (Fig. 2) and KBL-1 are also used for these purposes [Kotov, 2022; Suchkov, 2019]. In all these tools, the working bodies are made in the form of paddle or wire impellers. In the modernized cultivator KRL-1A, impellers are used, in which teeth are placed radially for caring for
plants up to 15 cm high. Some finger working bodies of the PRO are made in the form of freely rotating finger stars. The impellers are located symmetrically relative to the axis of a number of cultivated crops, inclined in a transverse-vertical plane to a number of crops at an angle of 0.1 rad, which ensures their rotation upon contact with the soil. Soil cultivation with such cultivators is carried out by saddling a number of crops [Bartenev et al., 2010; Goncharov et al., 2016].

Fig. 2. Rotary forestry cultivator KRL-1A.

There is information in the literature that indicates the shortcomings of the KRL-1M and KBL-1 cultivators. During their movement along a row of forest crops, loosened soil is displaced in the direction of movement of the unit and to the axis of the row, which leads to the accumulation and filling of seedlings up to 15 cm high with soil, and in plants 40–50 cm high and higher, when saddling the row, the apical bud, the bark is peeled off, lateral branches are broken. Damage to forest plantations, when working with such cultivators, is about 8%. In addition, these cultivators weakly destroy perennial weeds over 5 cm high [Bartenev et al., 2013; Zhdanov et al., 2011; Mashtakov et al., 2018].

The rigid connection of the KBL-1 cultivator to the tractor frame in a perpendicular plane to the axis of movement of the unit makes it difficult to copy the soil microrelief, which reduces the quality of its processing. In some rationalization solutions to this problem, the rigid connection is replaced by a hinged connection, which makes it possible to copy the micro relief well and cultivate the soil on slopes with a steepness of up to 0.2 rad.

The missile defence device loosens the soil and destroys grass in protective zones and rads on medium and light soils in terms of mechanical composition. These devices are installed on the main (base) cultivator, which allows simultaneous tillage in row spacing’s and protective zones.

In all of the listed tools for tillage in protective zones and rows, the radial clearance between the working bodies varies depending on the diameter of the crown of forest crops. With an increase in this diameter, when cultures reach 10-30 cm, the gap between the working organs is recommended to be set within 30-50 mm, and for crops with a height of 40 cm and above, the gap should be 50-80 mm. However, studies [Nartov, 1969] indicate that the fluctuations in the width of the protective zones are greatly influenced by the so-called microcurvilinearity of the rows, which is determined by the dispersion of seedlings in the rows at the time of planting, which occurs as a result of the displacement of seedlings towards from the longitudinal axis of the row. According to (Nartov, 1969), the width of
the scattering zone reaches 8-12 cm, but even this curvilinearity of the rows is not copied by tools, but causes a corresponding increase in the width of the protective zones.

Tools with passive working bodies of the cutting type KUN-4 and PRVN-72000 are used for soil care in rows. In these cultivators, the control of retractable working bodies in the form of flat-cutting paws is carried out by means of a servo hydraulic system, including a spool, remote hydraulic cylinders, a linkage system and mechanical probes.

The KUN-4 cultivator is designed for soil care simultaneously in the rows and between rows of crops on the plain and slopes up to 12 degrees. Rotary working bodies are installed in the center of the cultivator symmetrically, relative to its longitudinal axis, and automatic retractable sections are installed at the ends of the front frame bar. This cultivator has the following feature - when working with plants up to 100 cm high, the unit moves over the rows and processes one row and two row-spacings in one pass. With a crop height of more than 100 cm, the unit moves along the aisle and processes one aisle and two half-rows [Bartenev, 2017; Malyukov et al., 2019; Suchkov, 2019].

Adaptation PRVN-72000 is an addition to the vineyard plow PRVN-2.5A. This device with six plows processes in one pass a row-spacing with a width of 2.0-2.5 and two half-rows. The PRVN-11000 device is similar to the PRVN-72000 device, but it is installed on the PRVM-Z plow [Bartenev et al., 2010; Malyukov et al., 2019]. These devices work effectively when the height of cultivated crops is more than 1.5 m, in which the diameter of the stems is more than 20 mm and at a distance between plants in a row of 2 m or more. With a decrease in the distance in a row to 1 m, the number of dead weeds decreases to 38%, and the number of damaged cultivated plants increases from 0.4 to 2.9%.

For intensive destruction of weeds in protective zones and rows, 1-2-year-old crops, the PRANTAD machine (automatic mounted tractor active action weeder-ripper) or in the PR-2 modification was developed and manufactured. The principle of operation of the PR-2 weeder was based on surface wandering milling of the soil by active working bodies with a vertical axis of rotation. The working bodies of this weeder entered the gap between seedlings in a row. However, the complexity of the effective use of this machine lies in the fact that the program for controlling the working bodies during their entry and exit from a number of forest crops is based on the planting step. During planting, the planting step, for a number of reasons, has significant deviations from the established norm, and therefore the PR-2 weeder-cultivator produced poor soil cultivation around the seedling and was not widely used [Nartov, 1980].

There was an attempt to use the weeder-ripper PR-2 for tillage with narrowed protective zones. For these purposes, both beds, on which active working bodies are installed, were pivotally connected to each other by an adjusting rod, a gap was established between the working bodies, which made it possible to adjust the width of the protective zone in the range from 5 to 40 cm. by means of a hydraulic cylinder, which was controlled by the operator, they moved to the right and left of the axis of the row, which made it possible to copy the microcurvilinearity of the row in the horizontal plane, and this ensured tillage at the minimum allowable distance from the seedling. To protect the seedlings from damage and falling asleep, the working bodies were protected by protective covers. As a result of the operation of the weeder-ripper PR-2, a number of shortcomings were revealed, which boil down to the following: rotary working bodies of active action with a vertical axis of rotation copy the microrelief, but work only in clean areas. The main and main drawback of this freewheeler is the lack of an automatic control system for the working bodies. Manual control by an operator does not allow to increase operating speeds and therefore productivity.

At present, Novatek LLC produces an automatic hydraulic weeder RA-1 (Fig. 3). It is used to loosen the soil and remove weeds. This unit is hung either on the front or rear hitch of the tractor. The drive is carried out from the hydraulic system of the tractor. In contrast
to the weeder-ripper PR-2, the weeder RA-1 of the automatic control system for working bodies. The working body is able to move sideways at a distance of up to 40 cm using hydraulics. To protect seedlings from damage, the working body is equipped with a protective cover [Site: Agroserver (agroserver.ru)].

Fig. 3. Weeder automatic hydraulic RA-1.

The KFU-1.5A cultivator is designed for soil cultivation in row-spacings and rows of crops. It is hung from behind on the tractor "Belarus". This cultivator is equipped with an active working body in the form of a milling drum with L-shaped knives and passive paws for loosening the soil.

Copying the curvilinearity of the seed tape, when cultivating the soil between rows, is carried out by the operator using a hydraulic distributor installed directly on the cultivator near the operator's seat.

The design of the KFU-1.5A cultivator provides for soil treatment only in the nursery seed belts. Its working body moves in the transverse direction to the movement of the unit only by 10 cm and does not have the ability to till the soil by surface wandering milling. An operator is involved to control the working bodies, which leads to a decrease in the economic efficiency of the technology for caring for forest crops. In addition, manual control of the working bodies of the cultivator causes premature fatigue, which leads to an increase in plant damage.

For soil cultivation in nurseries, cultivators KFP-1.5 and FPSh-1.3 are used [Rodin et al., 2015], which are equipped with active working bodies in the form of cutters. The working bodies of these cultivators are equipped with L-shaped knives. Both cultivators provide tillage to a depth of up to 10 cm.

For the formation of ridges on the FPSh-1.3 cultivator, two bed-forming bodies in the form of skimmers with right- and left-hand turning blades and support wheels can be installed. The bed-forming device is raised and lowered by an external hydraulic cylinder, regardless of the rise of the cutter.

To care for single-row crops on temporarily waterlogged soils, heavily overgrown with herbaceous vegetation and overgrowth of tree species up to 2 cm in diameter, a forest milling cultivator KFL-1.4 is used (Fig. 4). Active milling drums serve as working bodies. Discs with L-shaped knives are rigidly fixed on the drum shaft, thereby ensuring their rolling over obstacles. When the cultivator moves, the L-shaped knives of the milling drums loosen the soil on both sides of the row of crops, cut weeds and small shoots and mix them with the soil. When skis run over microroughness, the milling drum, due to its hinged
suspension, is set to the desired position and provides copying of the microrelief. The total capture width is 1.4 m [Bartenev et al., 2013; Kotov, 2022].

Fig. 4. Cultivator milling forest KFL-1.4.

The milling cultivator KF-1.5 (Fig. 5), manufactured by TD Altai LLC, is designed for inter-row tillage. The working bodies are driven by the PTO of the tractor. Milling cutters serve as working bodies. Discs with L-shaped knives are rigidly fixed on the drum shaft. It is hung from behind on the MTZ-80/82 tractor [Website: Altai Trading House - supply of agricultural machinery (altaytd.ru)].

Fig. 5. Milling cultivator KF-1.5.

The cultivator KLB-1.7 (Fig. 6) is used to care for saplings and seedlings planted or sown mechanized in the bottom of furrows or on strips prepared by a cutter. It consists of a frame in the form of a rectangular bar, two disk batteries, a swivel device, a shock-absorbing device and ballast boxes. The cultivator is a tool that saddles a row of crops with disc batteries symmetrically located relative to the traction line [Kotov, 2022; Latysheva, 2015; Lysych et al., 2015; Malyukov et al., 2019; Posmetiev et al., 2013, 2015; Posmetryev et al., 2016; Zelikov et al., 2014].
Fig. 6. Forest furrow cultivator KLB-1.7.

The rotary device of the batteries allows you to adapt the cultivator to the transverse profile of the furrow and change the angle of attack. It consists of two pairs of plates with adjustment holes: front and rear, top and bottom. The front plate is fixedly attached to the frame, and batteries are attached to the racks of the rear plates. The tilt of the batteries is adjusted in accordance with the profile of the furrow (in the transverse-vertical plane towards the middle of the furrow) within the range of 0-20°.

The bottom plate is fixed to the battery case, and the top plate is pivotally attached to the frame. Changing the angle of attack of the disks within 0-30° is carried out by turning the lower plates relative to the upper ones and installing the bolts in the corresponding holes. Each battery is held in position by two damping springs. When hitting an obstacle, the batteries may deviate and then return to their working position. The actuation force of the safety device is adjusted by the tension of the springs. Disc batteries can be installed to work in a waddle and waddle. To do this, they are rearranged: left instead of right, and right instead of left. The cultivator is set up directly on the site of the forthcoming work. The angle of inclination of disk batteries towards a number of crops is set so that all disks are evenly deepened. The depth of processing (6-12 cm) should provide loosening of the soil and complete destruction of weeds in the cultivated strip. It is regulated by changing the angle of attack of the disk batteries.

Damage and destruction of cultivated plants by the KRT-3 cultivator (Fig. 7) is 30%, and by the KFL-1.4 cultivator - 43%. This is due to the clogging of the working organs of these cultivators with weeds and logging residues, which occurs after 12-15 m. At the KRT-3 cultivator, one side is usually clogged first. This causes the cultivator to move laterally, which leads to damage to the cultivated plants. Clogging of the working bodies of the milling cultivator KFL-1.4 occurs with cutting residues with a diameter of about 40 mm and a length of 250-350 mm. The degree of destruction of weeds in the tillage zone during the operation of a milling cultivator reaches 92.6%, and when the disk and tine cultivators are operated, it is 81-86% [Lysych et al., 2015]. The coefficient of soil structure, which characterizes the impact of the working bodies on the soil, indicates the efficiency of the disk working bodies. In a tine cultivator, with the indicated soil hardness, due to the insufficient rigidity of the springs of the safety mechanism, the angle of entry of the working bodies into the soil is violated, which leads to an increase in the deformation zone and obtaining large clods of soil.
In addition, the KRT-3 cultivator has low reliability. When meeting with stumps, the racks of the working bodies and wheels are deformed, and the cultivator paws themselves are often broken. Milling cultivator KFL-1,4- also has low operational reliability. In the process of work, the milling drum may break off when it meets a stump; breakage of working parts and drive chains, breakage of asynchronous clutch hinges [Zhirnov, 2022]. Disc cultivators in work on forest objects are more reliable. Disc working bodies easily roll over obstacles - stumps, roots, deadwood, logging residues. They are almost not clogged with plant and soil mass, stick less, wear out slowly.

4 Conclusion

From the above material it follows that passive rotary cultivators in the care of 1-3-year-old crops do not completely destroy perennial weeds, crops up to 10 cm high are covered with soil, while a significant percentage of their damage is observed. Cultivators with retractable working bodies are not able to cultivate the soil in the rows of forest crops of 1-3 years of age, since the control of their working bodies is designed for the contact of a mechanical probe with the stems of plants of considerable elasticity.

Thus, the conducted studies have shown that, under the conditions of not uprooted clearings, for the mechanization of caring for forest crops, tools with disk working bodies are the most acceptable.

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