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Comparative Agrotechnological Assessment of Disk Tillage Tools

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Abstract. Currently, in Krasnodar Territory, disk tools are most often used for surface tillage. The efficiency of using disk tools primarily depends on the design and technological layout of their working bodies, soil and climatic conditions of operation and the number of working passages through the field. The article presents an agrotechnical assessment of disk tillage tools based on open data from machine testing stations of the Russian Federation. Based on the results obtained, the main agrotechnical performance parameters that do not meet generally accepted requirements are determined.

1 Relevance of the study

The domestic and foreign agricultural machinery industry produces a huge number of different tillage tools with disk working bodies, which include disk huskers, mulchers, disk harrows and various combined units. All the listed tools have their own purpose and soil and climatic zones of use. At the moment, disk harrows have become the most widespread. The qualitative, energy and economic performance of disk harrows is influenced by their design and technological parameters, which depend on the characteristics of their design, soil and climatic zone of application and previous culture [16, 17, 22, 24]. The main advantages of modern disk harrows are their rather simple design, technological reliability, and relatively long service life of the working bodies until their final wear.

2 Problem statement

According to their purpose, disk harrows are divided into field, garden and swamp harrows, and according to the layout of the working bodies, they are battery-powered and on an individual rack [6]. On the territory of the Russian Federation, and particularly, in Krasnodar Territory, disk harrows with individual fastening of working bodies are the most common. A distinctive feature of this arrangement of disks is the possibility of their installation at an angle to the vertical, which reduces traction resistance, increases the penetration and patency of soil and crop residues in the space between the working bodies and the tool frame, and also increases the degree and uniformity of their mixing by lifting the formation to a greater height [18]. However, despite the significant similarity of the structural and technological layout of the working bodies of the known disk tools, the

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effectiveness of their application differs significantly not only in various technological operations, but in various soil and climatic conditions [12, 14, 15, 20, 23]. On the other hand, based on a comparison of the structural and technological layouts of the working bodies of disk tools and agrotechnological parameters of their work, it is possible not only to identify the best conditions and types of technological soil treatments, but also prospects for improving the efficiency of their work [19, 21].

3 Presentation of the main research material

The semi-trailer disk harrow BDP-6×2P (Fig. 1) manufactured by CJSC Rubtsovsky Spare Parts Plant is used as a tool for surface and basic tillage to a depth of up to 12 cm with simultaneous cutting and crushing of weeds and crop residues, humidity up to 30% and hardness up to 3 MPa [1].

Fig. 1. Disk harrow BDP-6×2P of CJSC Rubtsovsky Spare Parts Plant.

Disk harrow BDP–6×2P has a grip width of 6 m, is aggregated with an energy vehicle with a capacity of 175-200 hp and operates at speeds of 8-12 km/h. It consists of two rows of cutting units with spherical disks with a cut-out cutting edge with a diameter of 560 mm, mounted on an individual rack through bearing units equipped with two conical bearings. The cutting units are mounted in the frame through bushings welded into it with a longitudinal distance of 250 mm, have an adjustable angle of attack up to 30o, and are also mounted vertically at an angle of 10o. Slatted rollers are installed behind the cutting points for additional crumbling and leveling of the soil surface. The disk harrow is aggregated with an energy device using a trailed earring mounted on the bottom of the tool. A turnbuckle is installed between the bottom and the central bearing part of the frame, which allows us to align the tool frame in a horizontal plane during operation, and thereby ensure a uniform processing depth. Tests of the disk BP-6 = 2P were carried out at the Altai MIS, the results of which are presented in Table 1 [1].

Table 1. Performance parameters of the BDP-6×2P disk harrow.

#	Parameter	Value of a parameter
1	Arithmetic mean value of the processing depth, cm	to 15
2	Standard deviation of the processing depth, ± cm	1,9-2,6
3	Soil crumbling %, with a mass fraction of soil units in size, mm: – more 0 to 25 including – more 100	 53-63,2 0
4	Cutting of weeds, %	94,3-95,5
5	Uniformity of the soil surface, cm	4-4,8
6	Incorporation of crop residues, %	89,1-90,7
7	Working speed, km/h	9,72

8	Specific fuel consumption, kg/ha	3,95
9	Mass, kg	4275

After analyzing the data in Table 1, it can be concluded that in terms of the quality of crumbling and cutting of weeds, this disk harrow does not meet agrotechnical requirements, which indicates the need for additional passes of the unit. The poor quality of work is primarily due to severe operating conditions, i.e. soil and climatic conditions during testing, and secondly, the large distance between the working bodies, resulting in unprocessed areas, which can be seen from uncut weeds and insignificant impact on the formation, which is reflected in the low degree of its crumbling.

The Carrier disk cultivator (Fig. 2) manufactured by the Swedish company Väderstad is used as a tool for surface and basic tillage to a depth of up to 12 cm with simultaneous pruning and crushing of weeds and crop residues, humidity up to 35%, hardness up to 3.5 MPa and relief slope up to 10 °. Carrier 820 has a grip width of 7.9 m. It is aggregated with an energy facility with a capacity of 220-300 hp and operates at speeds of 10-14 km/h [7].

Fig. 2. The Carrier Väderstad disk cultivator.

The Carrier disk cultivator includes two rows of frontally positioned cutting units with conical disks with a diameter of 450 mm mounted on the transverse beams of the cultivator frame with a distance of 250 mm, with a constant angle of attack equal to 16 ° and an angle of inclination of the disk to the vertical of about 10 °. The disk working bodies are mounted on maintenance-free bearing assemblies on the outside of the disk, which are attached to the frame using a rack. The cross shafts are pivotally attached to the cultivator frame using brackets and pushers [7].

A rolling roller and brackets, as well as support wheels mounted on suspensions, are pivotally mounted in the rear part of the frame using brackets and rocker shafts. Jet rods are installed between the rows of transverse shafts with disk working bodies on each section, which allow the beam with cutting points to be displaced up to 5 cm horizontally. The traction shaft is pivotally connected to the frame. The aggregation of the disk cultivator is carried out through a towing eye mounted on the drawbar. During storage, the cultivator rests on a stand and is equipped with a system for limiting the depth of the working organs [7].

A distinctive feature of the Carrier disk cultivator is the use of conical disks of small diameter, which allows you to maintain the correct cutting angle during operation with any wear of the disk, as well as intensively affect the formation due to increased rotational speed. The installation of bearing assemblies on the outside of the disk allows to improve the permeability of the soil in the inter-disk space, as well as to reduce the energy intensity of the process. Fastening the cutting units to the frame with rubber dampers allows them to be bypassed by digging out when encountering a local incorporation or obstacle. Tests of the Carrier disk cultivator were carried out at the Kuban MIS, the results of which are presented in Table 2 [7].

Table 2. Performance parameters of the Carrier 820 disk cultivator.

#	Parameter	Value of a parameter
1	Type of work	Crumbling the soil layer after plowing
2	Arithmetic mean value of the processing depth, cm	11,2
3	Standard deviation of the processing depth, ± cm	1,9–2,6
4	Soil crumbling %, with a mass fraction of soil aggregates in size, mm: – more 0 to 25 including – more 25 до 50 including – more 50	 75 16,7 8,3
5	Cutting of weeds, %	100
6	Uniformity of the soil surface, cm	2,6
7	Incorporation of crop residues, %	100
8	Working speed, km/h	13,2
9	Specific fuel consumption, kg/ha	6
10	Mass, kg	7400
11	Soil humidity, %	9,7–33,4
12	Soil hardness, MPa	0,53–0,83

Analyzing the data in Table 2, it can be concluded that the Carrier disk cultivator crumbles the soil layer in one pass when cutting the soil layer after plowing into fractions up to 25 mm in size within 75%, which does not meet agrotechnical requirements. The noted incorporation of crop residues in 100% characterizes the working conditions without their content in the upper layer and on the soil surface.

The Catros compact disk harrow (Fig. 3) manufactured by Amazone is used as a tool for tillage to a depth of up to 15 cm after direct combination, cutting layers after plowing, pre-sowing preparation and incoproration of crop and plant residues of the main and intermediate crops, with a relief slope of up to 15%, humidity up to 35% and the soil hardness is up to 3.5 MPa. The capacity of the power equipment for aggregation depends on the width of the harrow and varies from 125 hp for 4 m to 300 for 7.5 m. The operating speed is up to 12 km/h [8].

Fig. 3. Catros compact disk harrow.

When working to a depth of 3 to 12 cm, the Catros disk harrow is equipped with spherical smooth disks with a diameter of 460 mm, and for working to a depth of 5 to 15 cm, spherical cut-out disks with a diameter of 510 mm. The distance between adjacent working bodies in one row is 250 mm.

The supporting part of the Catros harrow structure is the central frame, to which the left and right sections are connected by a hinge joint, on which the cutting points are mounted in 2 rows frontally. The cutting units are attached to the longitudinal shafts of the sections using rubber dampers, similar to the Carrier disk cultivator, which allows them to copy the surface relief and deviate when colliding with local incorporations and obstacles. The disks are bolted onto a maintenance-free bearing assembly on the outside of the disk.

In addition to the cutting units, wedge-shaped rollers equipped with brackets for cleaning from stuck soil are installed in the rear of the section using special frames. The sections are moved to the working position by hydraulic cylinders. In the front part of the frame, a drawbar with a trailer shackle is pivotally installed, with the help of which it is aggregated with a tractor. Transportation of the Catros harrow, as well as transfer to the working position, is carried out by a folding undercarriage. In order to prevent the formation of piled ridges and collapsing furrows in the joints between the harrow passages, the outer disks have individual height adjustment. To increase the sinking capacity of the working bodies when working on hard, dry soils, the Catros disk harrow is additionally equipped with ballast loads.

A distinctive design and technological feature of the Catros disk harrow is the installation of disks with different angles of attack, the front row has an angle of 17 ° and the rear 14 °. When equipping cutting units with MultiSet hubs, the angle of inclination of the disk working bodies to the vertical is adjusted within 11, 13 or 17o. In addition, for operation at shallow depths, the harrow is equipped with a system for shifting the rear row relative to the front by rearranging the thrust finger along the holes, which allows you to change the degree of overlap of the passages of neighboring working bodies. All these design and technological features make it possible to change the degree of impact of the working bodies on the soil within a wide range, which will have a positive effect on the degree of crumbling of the formation and incorporation of crop residues, as well as the energy intensity of the process. Tests of the Catros disk harrow were carried out at the Kuban MIS, the results of which are presented in Table 3 [8, 13].

Table 3. Performance parameters of the Catros disk harrow

#	Parameter	Value of a parameter	
		Leveling of winter tillage	Husking of corn stubble 3 trace
1	Arithmetic mean value of the processing depth, cm	8,5	10,2
2	Soil crumbling %, with a mass fraction of soil aggregates in size, mm: – more 0 to 10 including – more 10 to 25 – more 25 to 50 – more 50	 69,8 20,4 8,9 0,9	general value 91,1 8,9
3	Cutting of weeds, %	–	100
4	Uniformity of the soil surface, cm	1,6	1,8
5	Incorporation of crop residues, %	88,3	76,2
6	Working speed, km/h	8,5	14,9
7	Specific fuel consumption, kg/ha	5,6	6,5
8	Mass, kg	6100	3800
9	Soil humidity, %	24–27	–
10	Soil hardness, MPa.	0,62–0,73	–

After analyzing the data in Table 3, it can be concluded that the degree of cutting and incorporation of weeds, the uniformity of the field surface as well as the depth of soil processing meet the established requirements. Complete cutting of weeds is achieved, first of all, by shifting the rear row of disk working bodies, and the quality of crumbling is due to repeated passes of the unit and the use of a disk with a diameter of 460 mm. Thus, when husking stubble of long-stemmed row crops with a Catros compact disk harrow, quality parameters are achieved during the second or third pass of the unit.

As a result of the technological process of leveling the winter tillage , the obtained quality parameters fully comply with the established requirements, which is explained by the favorable soil and climatic conditions of work, as well as pre-plowing, as a result of which the degree of soil crumbling was close to or corresponded to the required.

Disk harrows of the Rubin series (Fig. 4) manufactured by Lemken are intended for surface, basic and pre-sowing tillage for grain and industrial crops to a depth of up to 14 cm with simultaneous grinding and incorporation of crop residues, as well as for incorporation of intermediate crops. The Rubin series disk harrows operate at soil moisture up to 35%, hardness up to 3.5 MPa and terrain slope up to 10 °. The Lemken Rubin 9/600KUA double-row disk harrow is aggregated with an energy facility with a capacity of 210-300 hp with an operating speed of up to 12 km/h.

Fig. 4. Lemken Rubin 9/600KUA disk harrow

The main working body of the Rubin 9/600KUA harrow is a spherical pointed disk with a cut-out cutting edge with a diameter of 610 mm, having a constant angle of attack of 18o and an angle of inclination to the vertical of 22o. The working bodies are mounted on maintenance-free bearing assemblies on the outside of the disk and are attached to the harrow frame using a curved rack with a spring-loaded suspension. The distance between adjacent cutting points in the horizontal plane is 250 mm.

A distinctive design and technological feature of the Rubin 9/600KUA disk harrow is the installation of large-diameter disk working bodies, which allows, with their large angle of inclination to the vertical, to place bearing units outside the sphere of the disk without the risk of dragging the soil in front of it and work to a great depth. The orientation of the disks with an angle of 22 ° to the vertical allows, during processing, to move the soil along the radius of the disk to a greater height until it is dropped, which increases the degree of crumbling and mixing of the soil with stubble and plant residues. The spring-loaded suspension will allow you to copy the terrain of the soil, protect the cutting points from breakage when they meet with local incorporations, and will also create vibration, which will reduce the specific traction resistance. The use of spring harrows in the design in combination with rolling rollers will lead to better crumbling of the soil, as well as its leveling. In addition, the working bodies are installed symmetrically relative to the longitudinal axis of the tool, which will increase the directional stability of the tool and affect the completeness of cutting weeds and also the uniformity of the soil surface. Tests of the Rubin 9/600KUA disk harrow were carried out at the Kuban and Northwestern MIS, the results of which are presented in Table 4 [9, 13].

Table 4. Performance parameters of the Rubin 9/600 KUA disk harrow.

#	Parameter	Value of a parameter	
		Husking of winter wheat stubble 1 trace	Husking of corn stubble 1 trace
1	Arithmetic mean value of the processing depth, cm	12	10,1
2	Soil crumbling %, with a mass fraction of soil aggregates in size, mm: – to 50 – more 50	 89,5 10,5	 81,3 18,7
3	Cutting of weeds, %	100	100
4	Uniformity of the soil surface, cm	2	1,5
5	Incorporation of crop residues, %	61,9	62,5
6	Working speed, km/h	11,5	8,8
7	Specific fuel consumption, kg/ha	6,2	5,8
8	Mass, kg	9040	5820
9	Soil humidity, %	–	16–21
10	Soil hardness, MPa.	–	0,78–1,15

The data obtained as a result of tests of the Rubin 9/600 KUA disk harrow confirm the effectiveness of the design and technological solutions used, which is confirmed by the parameters of cutting weeds, the uniformity of the field surface and the degree of incorporation of plant residues. However, the values of the degree of soil crumbling also indicate the need for additional passes of the unit.

Four-row disk harrows, usually called discators, as well as three-row ones, are usually produced by agricultural machinery manufacturers of the Russian Federation and CIS countries, which is due to a number of reasons. First of all, these include soil and climatic conditions. The soils of most European countries are characterized by lighter conditions. Such soils are easier to cultivate, i.e. their shift occurs by a large amount, and lifting and husking requires less energy consumption. This fact allows you to place the working bodies at a great distance from each other on the same beam while maintaining the performance in one pass, in particular the continuity of processing. On the soils of Krasnodar Territory, these parameters are much higher, which leads to the need for convergence of working bodies. At the same time, convergence leads to an increase in the likelihood of clogging the inter-disk space, as often happens when battery tools are operating. It should be noted that reducing the row, i.e. reducing the longitudinal length of the frame, is advisable both from the point of view of material consumption, as well as from the side of exchange rate stability and energy consumption. The second reason can be attributed to the unjustified use of structural and technological parameters in the design.

The disk harrow BDM-4×4P (Fig. 5) produced by the company "BDM-AGRO" is designed for basic and pre-sowing tillage with a moisture content of up to 30% and a hardness of up to 3.5 MPa, with a natural field slope of up to 10° when cultivating grain, technical and forage crops using traditional and minimal technologies.

Fig. 5. Disk harrow BDM–4×4P.

The main working body of the BDM-4×4P disk harrow is a spherical disk with a diameter of 560 mm with a cut-out cutting edge mounted on an individual rack, having an adjustable angle of attack within 0-25 ° and a constant installation angle to the vertical equal to 10 °. The working bodies are mounted in bushings on the tool frame frontally in four rows with a row distance of 400 mm. This arrangement of the working bodies makes it possible to cultivate the soil in severe soil and climatic conditions without freezing them. Tests of the BDM-4=4 P disk harrow were carried out at the Kuban and Northwestern MIS, the results of which are presented in Table 5 [2].

Table 5. Performance parameters of the BDM-4×4P disk harrow.

#	Parameters	Value of a parameter	
		Husking of corn stubble 1 trace	Husking of corn stubble 2 trace
1	Arithmetic mean value of the processing depth, cm	7,7	11,9
2	Soil crumbling %, with a mass fraction of soil aggregates in size, mm: – to 25 – more 25	 46,7–67,2 32,8–53,3	 71,1–83,4 16,6–28,9
3	Cutting of weeds, %	100	100
4	Uniformity of the soil surface, cm	2,1–3,4	2,1–3,4
5	Incorporation of crop residues, %	–	–
6	Working speed, km/h	8,5–10,3	8,5–10,3
7	Specific fuel consumption, kg/ha	5,1–9,6	5,1–9,6
8	Mass, kg	2730	2730
9	Soil humidity, %	13,2–15,7	13,2–15,7
10	Soil hardness, MPa.	2,9–5	2,9–5

The analysis of the presented data allows us to conclude that the BDM-4×4P disk harrow in conditions of increased soil hardness (2.9-5 MPa) can be processed in accordance with agrotechnical requirements in only 2 passes of the unit. The increased hardness also affects the high energy intensity of the process.

The same results are obtained when working with disk harrows with other technological schemes for the layout of working bodies [3, 4, 5, 10, 11].

4 Conclusions

After conducting a comparative agrotechnical assessment of disk tools, it can be concluded that when working in severe soil and climatic conditions, they are not able to carry out soil tillage in accordance with agrotechnical requirements for husking and disking stubble operations in one pass of the unit. Among the parameters of the quality of disk harrows, it is possible to single out the requirements for the degree of soil crumbling, which modern disk tools do not correspond to when working in one track for the conditions of Krasnodar Territory. Four-row disk harrows are among the most suitable for working in the soil and climatic conditions of Krasnodar Territory. In addition, the disadvantages of four-row disk harrows include the inability to incorporate plant and crop residues in the required volume. Thus, to increase the efficiency of four-row disk harrows, it is necessary to increase the degree of crumbling of the soil by working bodies, as well as to increase the degree of crop and plant residues incorporation.

References

1. Disk semi-trailer harrow BDP-6=2 N [Text] / Ministry of Agriculture of the Russian Federation. Federal State Budgetary Institution Altai State Machine Testing Station, - test report dated 12.09.2018 No. 01-21-18 (5020592).
2. Disk harrow upgraded BDM-4x4P (discator) [Text] / The Ministry of Agriculture of Russian Federation, Federal State Budgetary Institution Kuban State Machine Testing Station, - test report dated 06.10.2015 No. 07-39-2005 (4020422). – P.4.
3. Disk harrow BDM-6x4PK [Text] / Ministry of Agriculture of the Russian Federation. Federal State Budgetary Institution Kuban State Machine Testing Station, - test report dated 11/21/2017 No. 07-55-2017 (5020662). – P.4.
4. Disk harrow Rumba 5×2PC [Text] / Ministry of Agriculture of the Russian Federation, Federal State Budgetary Institution Kuban State Machine Testing Station, - test report dated 05.12.2018 No. 07-98-2018 (5020922). – P.5.
5. Disk harrow BDM-7x3PK SHK [Text] / The Ministry of Agriculture of the Russian Federation. Federal State Budgetary Institution Vladimir State Machine Testing Station, - test report No. 03-66-18 (5020642) dated 11/21/2018. – P. 4.
6. Klenin N.I. Agricultural machines [Text]: textbook / N. I. Klenin, S. N. Kiselyov, A. G. Levshin: – M.: KolosS, 2008 – 816 p.: ill. – (Textbooks for higher education students). ISBN 978-5-9532-0455-2.
7. Test report of the imported sample of the Väderstad CR 820 disk cultivator [Text] / Ministry of Agriculture of the Russian Federation. Federal State Budgetary Institution Kuban State Machine Testing Station, - test report dated 03.12.2018 No. 07-93-2018 (6240552). – P.5.
8. Test report of an imported sample of the AMAZONE CATROS 7501-2T compact disk harrow [Text] / Ministry of Agriculture of the Russian Federation. Federal State Budgetary Institution Kuban State Machine Testing Station, - test report dated 10.12.2018 No. 07-104-2018 (6240712). – P.6.
9. Test report of the Rubin 9/600 KUA disk harrow [Text] / The Ministry of Agriculture of the Russian federation. Federal State Budgetary Institution North-Western State Zonal Machine Testing Station, – test report dated 09/19/2017 No. 10-09-2017 (5020422). – P.4.

10. Protocol of periodic tests of the disk harrow upgraded BDM-7x3PK SSR [Text] / Ministry of Agriculture of the Russian Federation. Federal State Budgetary Institution of the Russian Federation, Vladimir State Machine Testing Station, - test report No. 03-06-16 (5020302) dated 07/13/2016. – P.31.
11. Protocol of periodic tests of the disk modular harrow BDM-5x4/09 [Text] / Ministry of Agriculture of the Russian Federation. Federal State Budgetary Institution of the Russian Federation, Vladimir State Machine Testing Station, - test report No. 03-42-16 (5020352) dated 10/21/2016. – P. 32.
12. Sokht K. A. Soil structure. Technologies and equipment. Problems and solutions [Text]: textbook / K. A. Sokht, E. I. Trubilin, V. I. Konovalov. – Krasnodar: KubSAU, 2018. – P.116.
13. Comparative analysis of the technical level of disk harrows based on the results of tests at machine testing stations [Text] / Ministry of Agriculture of the Russian Federation. Federal State Budgetary Institution State Testing Center, Solnechnogorsk, 2014. – P. 66.
14. Tarasenko B. I. Tillage [Text]: textbook / B. I. Tarasenko, A. S. Naydenov, N. I. Bardak, V. V. Tereshchenko. – Krasnodar: KubSAU, 2015. – P.176.
15. Tarasenko B. I. Increasing soil fertility in Kuban [Text]: monograph / B.I. Tarasenko. – Krasnodar: KubSAU, 2014. – P.130.
16. Konovalov, V. Analytical study of the design parameters of the grinding unit of disk harrows / V. Konovalov, S. Konovalov, V. Igumnova // IOP Conference Series: Earth and Environmental Science : 12th International Scientific Conference on Agricultural Machinery Industry, INTERAGROMASH 2019, Rostov-on-Don, 10–13 сентября 2019 года. Vol. 403. – Rostov-on-Don: Institute of Physics Publishing, 2019. – P. 012086. – DOI 10.1088/1755-1315/403/1/012086. – EDN PTSUKR.
17. Konovalov, V. Influence of Design and Technological Parameters of Disk Working Bodies on the Height of the Crest of the Bottom of the Furrow/ V. Konovalov, S. Konovalov// MATEC Web of Conferences 346, 03006 (2021) ICMTMTE 2021 – DOI 10.1051/matecconf /202134603006
18. Konovalov, V. Kinematic Analysis of a Disk Working Body with a Changing Radius of Curvature/ V. Konovalov, S. Konovalov, V. Baradakov// MATEC Web of Conferences 346, 03007 (2021) ICMTMTE 2021 – DOI 10.1051/matecconf /202134603007– DOI 10.1051/e3sconf/202128507003
19. Konovalov, V. Analysis of Development Trends of Disk Tillage Organs for Increasing the Degree of Soil Crumbling/ V. Konovalov, S. Konovalov, V. Baradakov// International Conference on Modern Trends in Manufacturing Technologies and Equipment 2021 AIP Conf. Proc. 2503, 030008-1–030008-9; – DOI 10.1063/5.0104948
20. Konovalov, V. Tillage and Creation of Soil Structure in the Conditions of Krasnodar Territory/ V. Konovalov// International Conference on Modern Trends in Manufacturing Technologies and Equipment 2021, AIP Conf. Proc. 2503, 030009-1–030009-4; – DOI 10.1063/5.0105395
21. Konovalov, V. Analysis of research on soil destruction criteria during its interaction with working bodies/ V. Konovalov// E3S Web of Conferences 285, 07003 (2021) ABR 2021, – DOI 10.1051/e3sconf/202128507003
22. Masienko, I. Theoretical study of the forced oscillation effect on subsoil tillage / I. Masienko, A. Vasilenko, L. Eranova // E3S Web of Conferences. – 2020. – Vol. 193. – P. 01028.

23. Sokht, K. Uniformity of the soil tillage depth with tools with disk working bodies/ K. Sokht, V. Konovalov// E3S Web of Conferences 398, 01012 (2023) – DOI 10.1051/e3sconf/202339801012 ABR 2023
24. Rykov V. B. System of energy criteria in the justification of technical units for field production / V. B. Rykov, S. I. Kambulov, E. I. Trubilin, Yu. K. Kastidi // E3S Web of Conferences. – 2020. – Vol. 193. – P. 01008