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Selection of operating modes of tillage implement with ring working tools by criteria of quality and energy inputs

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Abstract. Improving the tillage methods, machines and equipment to increase their efficiency is an urgent task. Tillage implements should provide high-quality tillage, save energy and improve the yielding capacity of cultivated crops. The study purpose was to obtain the experimental data, which would reveal the variation patterns of energy parameters and agrotechnical indicators of the tillage implement operation, and to identify the rational operation modes under specific operating environment. The study object was the developed tillage implement with ring working tools PM-2/DK for pre-seeding tillage. The study subject was to obtain the variation patterns in energy and agrotechnical indicators of the designed modification of the tillage implement with the ring working tools teamed with MTZ-920 tractor. The study used the modern methods of theory and experimentation to identify the main quality indicators of the technological process of surface tillage, as well as to determine the energy parameters of the machine, to generalize them, and to analyze the experimental data obtained. The variation patterns of energy and agrotechnical indicators were revealed, the rational operation modes of the tillage implement were justified, namely, working speed V=2.8-3.3 m/s; installation angle of the ring working tools α=15-22°; energy inputs of the technological process E_i = 373.80-431.18 MJ/ha.

1 Introduction

Priority tasks in modern agricultural engineering today are the development of designs of technical means on the basis of which it is possible to use new highly efficient energy-saving and environmentally sustainable technologies in crop production, which allow increasing labor productivity, significantly increasing crop yields, creating favorable conditions for plant growth, reducing costs and losses during tillage, sowing, fertilizing, harvesting, while ensuring environmental standards of safety and labor protection.

A team of scientists in the system of the Russian Academy of Sciences has formed a new technological system of functional modular tillage machines and tools [1] that provide

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high profitability in various climatic conditions, high productivity and energy efficiency in comparison with foreign analogues.

Anti-arid moisture-accumulating ecological methods of tillage have been developed [2, 3], which reduce the cost of grain production by up to 50 %.

The authors of the work [4] developed a model of the technological process of soil cultivation, justified the initial and boundary conditions of its functioning. The results obtained by the authors allow to optimize the design and technological parameters of the working bodies of machines using computer programs.

The authors of the work [5] developed agroecological principles for the formation of a zonal system of soil tillage. It is established that during the definition of a technology or process of crops cultivation it is important to rely on new methods for the differentiation of the developed methods and approaches to the tillage taking into account some important factors such as features of the agricultural landscape, properties, and degree of soil fertility, it is necessary to accurately assess the biological features of crops, the possible change in the process of erosion, phytosanitary soil condition and hydrological conditions.

Research has established the effectiveness of using multifunctional tillage and sowing units, which reduce operating costs by 48-71%, fuel consumption by 41-76%, and labor costs by 72-80 % [6].

It was found that strip tillage has a positive effect on protecting the soil from erosion, increasing the front angle between the row cleaner discs, and does not significantly affect CO_2 emissions and fuel consumption per unit of area under tillage [7].

The patterns of changes in agrotechnical indicators and energy parameters of the tillage implement for deep soil loosening without soil overturning in conditions of increased moisture in the North-Western zone of Russia are revealed [8].

The design of a tillage roller-leveler was developed, which provides an increase in the amount of agronomically valuable fraction by 4% on light loamy soils and an increase in the structural coefficient by 0.66 and 0.55 units [9].

The authors' study [10] reflects the results of evaluating the traction force of tillage machines, a model for calculating the traction force and the required power of a disk plow is developed.

The authors of the work [11] established rational values of the soil crumbling coefficient as a random value, which in turn depends on the potential energy accumulated by the soil, while the physical properties of the soil also have a significant impact on crumbling. It was found that the accumulation of energy causes cracking, which leads to crumbling of the soil surface.

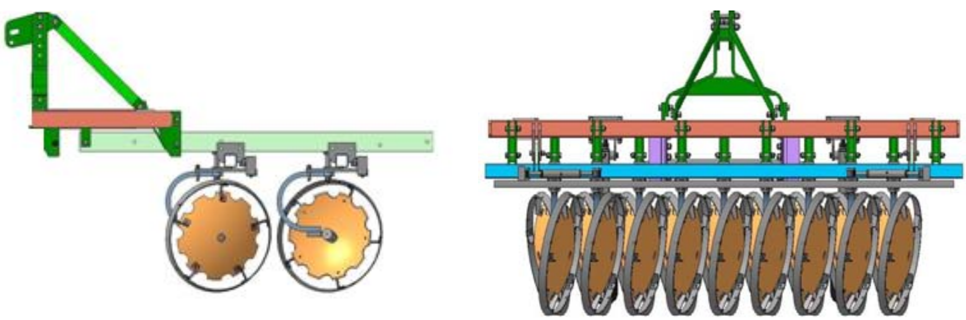
In crop production, a significant share of energy expenditure from 35 to 45%, depending on the cultivation of a particular crop, goes to tillage. With the existing variety of different designs of agricultural machines, it is possible to carry out a variety of technological works, while they do not always and do not fully meet the specified agronomic and agrotechnical requirements for surface tillage. One of the main negative factors obtained on the basis of practice is the high ridges of the field during its implement tillage, as well as the unloading of the upper soil layer, and here there is a fairly high energy intensity of the process itself. At the same time, in the vast majority of technologies related to the cultivation of various grain crops, pre-sowing tillage plays a key role, thereby having a significant impact on the profitability of production of a particular product.

Consequently, the improvement of applied methods, technical means and tools in surface treatment operations should provide a significant increase in the quality of their work, estimated by increased productivity of cultivated crops, while reducing all types of energy consumption for the implementation of appropriate technologies.

In 2012-2018, in the IEEP – branch of FSBSI FSAC VIM a number of modifications of tillage machines based on new designs of working elements for the conditions of the zone of increased moisture characteristic of the North-West of the Russian Federation.

During the research, the main technological and design parameters of the family of universal implemented tillage units created on a single frame structure based on the block-modular design principle were justified, and the quality indicators of the technological process that meet the agrotechnical requirements were determined.

One of the latest developments that would determine the completeness of the process, conducting the finishing operation in the system of preparing the soil for grain crops sowing was the creation in 2019 of an experimental sample of a tillage machine with ring working elements PM-2/DK (Fig. 1), which should replace or create technical competition with traditional units for sowing tillage.



a) b)

Fig. 1. Structural diagram of a tillage tool with working elements in the form of rings
(a - side view, b - rear view)

Laboratory and field studies conducted on the territory of the experimental production base of the institute have shown that the tillage implement provides high-quality soil treatment in accordance with the requirements of agricultural technology and can be used for pre-sowing tillage and its primary processing during the restoration of fallow lands.

To improve the efficiency of the proposed implement with ring working elements for pre-sowing tillage, it became necessary to determine energy and agrotechnical indicators and select rational modes of its operation.

2 Material and methods

In the course of research, modern methods of theory and experiments were used to identify the main indicators of the quality of the technological process of surface tillage, as well as to determine the energy parameters of the machine, generalize them, and analyze the experimental data obtained.

The purpose of this research is to obtain experimental data to reveal the patterns of changes in energy parameters and agrotechnical indicators of the operation of the tillage implement studied and the selection of rational modes of its operation for specific operating conditions.

During the energy evaluation of the PM-2/DK experimental sample with working elements in the form of rings, the following parameters and indicators were measured, such as:

- traction resistance of the machine;
- fuel consumption per hour;

- angle of rings attack;
- machine speed;
- tillage depth;
- degree of soil loosening;
- weed infestation of the field;
- degree of weeds destruction.

The conditions for conducting research, as well as the physical and mechanical properties of the agricultural background of the site where the unit was studied, are presented in table 1.

Table 1. Research conditions

Indicator	Measuring unit	Indicator value /
Ambient air temperature	^{0}C	12-15
Site area	ha	2.5
Field track length	m	100
Absolute soil humidity	%	24-26
Relative air humidity	%	70-75
Average wind speed	m/s	2-3
Wind direction	-	West, South-West
Soil type	-	Medium loamy sod-podzolic
Field relief	-	1-2^o
Number of stones	pcs/m^2	0.005
Average stone size	mm	350
Field infestation	pcs/m^2	284
Previous operation	-	Disking
Soil hardness before treatment in a layer of 0-15 cm	MPa/ (kg/cm^2)	0.82/8.2

Figure 2 shows the implement under study for pre-sowing treatment with ring working elements in the process of working on the experimental fields of the Institute.

Fig. 2. General view of the implement with ring working elements in the process of pre-sowing tillage.

For the energy assessment of the PM-2/DK tillage unit, the measurement and information system IP 264 RosNIITiM (Russian Research Institute for Testing Agricultural Technologies and Machines) was used. The following indicators were recorded in the steady-state mode of operation of the MTA with 3-fold repetition:

– number of motion sensor pulses per second I_{nc}, imp.;

– number of motion sensor pulses for each experience, $I_n$imp.;

– average duration of the experiment T, s.

- instantaneous value of the channels of the S_{mg} force sensor, mV and the ring position sensor as the working body S_m, mV.

The necessary indicators of the quality of the technological process of tillage were determined in accordance with the existing agricultural requirements for the production of mechanized works in the Russian Federation.

Figure 3 shows the agricultural background of the field section before and after processing with the experimental sample PM-2/DK.

Fig. 3. Agricultural background of the field area before and after the passage of the machine.

Figures 4 and 5 show the process of taking soil samples to determine soil moisture and determining the amount of weeds per 1 square meter of the field.

Fig. 4. Soil sampling to determine soil moisture.

Fig. 5. Determination of the amount of weeds per 1 m^2 of the field.

The energy intensity of the technological process of pre-sowing tillage was determined by the well-known formula [8]:

$$E_i = E_p + E_o + \frac{E_T+E_j+E_m}{W_{ch}}, \tag{1}$$

where E_p – direct fuel and energy costs, represented as the fuel consumption of the energy means, MJ/ha;

E_o – costs of energy contained in fertilizers, pesticides, seeds, herbicides, MJ/ha;

E_T– energy consumption of the tractor per unit of unit operation time, MJ/h;

E_j – energy costs (live labor) per unit of time, MJ/h;

E_m – energy intensity of the tillage machine per unit of operating time, MJ/h;

W_{ch} – productivity of the tillage unit, ha/h.

The productivity of the MTZ-920+PM-2/DK tillage implement for 1 hour of shift time was determined by the classical expression [8]:

$$W_{ch} = 0{,}1B_r V\tau, \tag{2}$$

where B_r – machine coverage, m;

V- operating speed, m/s;

τ – shift performance coefficient.

The general technical characteristics of the studied technical means for pre-sowing tillage are presented in table 2.

The terms of reference for the design of the machine provided for the passage of a number of technological operations: pulling out the weeds, their separation from the root part, and, accordingly, from the soil, as well as loosening and surface leveling of the field, while the change in the depth of tillage was set by the corresponding angle of attack of the ring fixed on a standard spherical disk.

Table 2. General technical characteristics of PM-2/DK

No.	**Parameter**	**Indicator value**
1	Type of tool	attached
2	Performance per hour of shift time, ha/hour	1.5-2.1
3	Operating speed, m/s (km/h)	1.4-3.33(9-12)
5	Working coverage, m	2
6	Processing depth, cm	5-12
7	Number of working elements, pcs.	18
8	Space between the working elements, mm	240
9	Overall dimensions, mm: length width height	 1860 2300 1300
10	Weight, kg	1250
11	Traction class of a tractor, ts	1.4

Statistical processing of experimental data was carried out according to the method described in the work [12].

3 Results and discussion

To select the rational modes of operation of the tillage machine by working elements in the form of rings, two main indicators were used as efficiency criteria: high quality and energy intensity of the technological operation of pre-sowing tillage.

Based on the results of the energy assessment, the traction resistance of the unit and the process quality indicators were determined, which are described below.

Figure 6 shows the dependence of the traction resistance Ra of the tillage tool on the speed V of its movement at different values of the angles of attack α of the ring working elements.

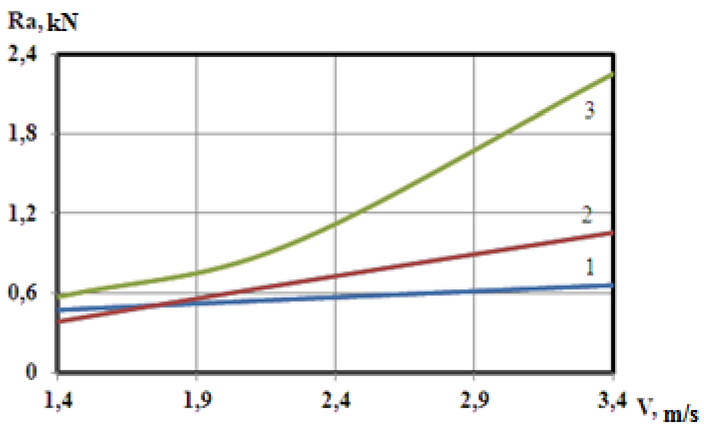


Fig. 6. Dependences of the traction resistance Ra of the tillage implement at the speed V when setting the angles of attack α of the rings: 1 - 15^0, 2 – 20^0, 3 - 25^0

Experimental data give an idea that due to the change in the speed of movement V, the traction resistance Ra of the tillage machine increases along slightly concave curves 1 and 2. At the same time, with a change in the angle of attack α by 5^0 (curve 1) to 20^0 (curve 2), the Ra parameter increases proportionally to 42%, and when the angle of attack is set to 25^0 (curve 3), the resistance intensity increases sharply by 3 times. This is due to the increase in the frontal area of the working surface of the rings with their complete overlap and the maximum possible depth in the soil layer.

In the course of conducting experimental tests, agrotechnical indicators of the unit with ring working elements that are important for surface tillage were determined: average values of the depth of processing, the degree of weed destruction, soil crumbling at the main speed modes of operation at certain values of the angle of attack of the machine rings.

Figure 7 shows the dependences of changes in the depth of tillage h from the speed of movement V of the unit at fixed values of the α angle of attack of the rings.

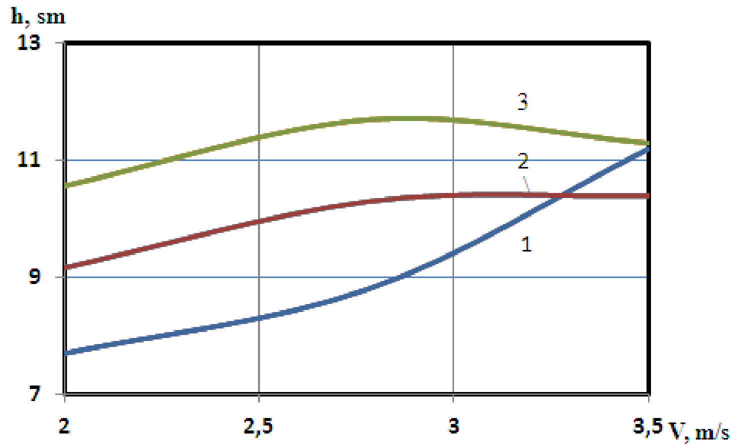


Fig. 7. Dependences of the depth of tillage h on the speed of movement V of the tillage machine at the corresponding α angles of attack of the rings: $1\text{-}15^0$, $2 – 20^0$, $3 - 25^0$

Analyzing the results of the experimental data in figure 7 on the depth of tillage, it should be noted that when the α angle of attack of the ring working elements is set to 15^0 (curve 1), a smooth increase in h to 11.3 cm is observed with an increase in the speed V of the machine movement in the measured range.

When the speed of the implement is 2.7 m/s or more and the α angles of attack of the rings 20^0 and 25^0 (curves 2, 3) are set, there is a stabilization of the depth of tillage h in the region of 10.7 cm ($\alpha=20^0$) and 11.7 cm ($\alpha=25^0$), and then at a speed of 3 m/s - a slight decrease (curve 3). The reasons for this reduction of the working depth h for angles of attack of the rings 20^0 and more, lie in the increase of the total resistance of the working elements due to the increased area of the working surface of the ring and the lack of cutting process of the soil and the presence of the effect of surface soil layer build-up with plant residues.

Figure 8 shows graphs of the dependence of the degree of weeds destruction Cy with ring working elements on the speed V of the machine at different α angles of attack.

From these data it follows that with increasing speed to 2.9 m/s at an angle α of 10^0 (curve 1) and to 2.8 m/s at an angle α of 15^0 (curve 2) the degree of weeds destruction is in the range of 94% - 98%, respectively, which determines the high efficiency of the operation, with a further increase in implement speed V the efficiency of the rings decreases, as a complete overlap of the two rows occurs only when the angle of attack α is 20^0, which confirms the presence of the horizontal line on the chart, regardless of the tool speed (curve 3).

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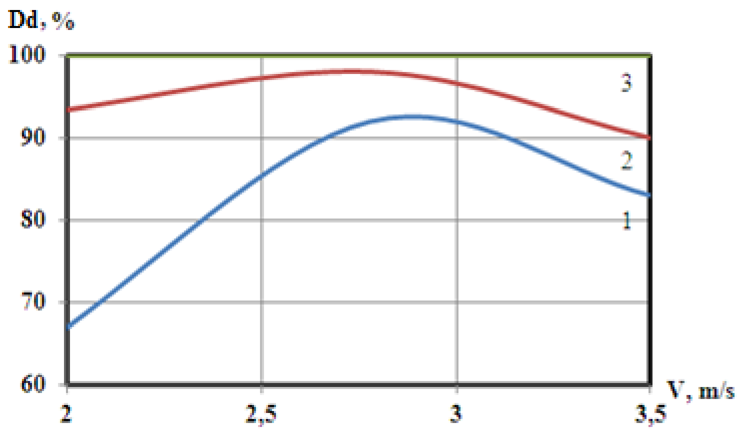

Fig. 8. Degree of weeds destruction Dd depending on the implement speed V when setting the appropriate α angles of attack: 1 - 10^0, 2 – 15^0, 3 - 20^0

Graphic dependences of the degree of soil crumbling Co with ring working elements on their corresponding α angles of attack at a fixed implement speed V are shown in figure 9.

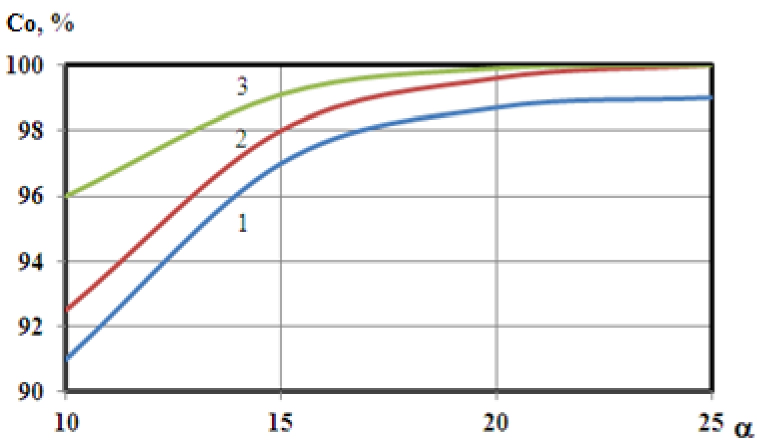

Fig. 9. Dependences of the degree of soil crumbling Co on the α angles of attack of the rings at different implement speeds: 1 - 1.94 m/s, 2 - 2.78 m/ s, 3 - 3.33 m/s

Experimental data and dependences (figure 9) indicate that the degree of soil crumbling at the angle of attack of the rings 20^0 and higher at three operating speeds is in the range of 98-100%.

The detailed analysis of the considered experimental data shows that the presented values of agrotechnical indicators exist within the appropriate limits of agricultural requirements that are imposed on pre-sowing tillage.

Based on the experimental data obtained using the Lagrange interpolation formula, we determined the empirical dependences of the average values of agrotechnical and operational indicators of the tillage machine for pre-sowing soil preparation (tables 3 - 6).

Table 3. Empirical dependences for determining the average value of the traction resistance Ra on the speed V of the tillage unit at fixed α angles of attack of the rings

Parameter	Argument	Calculation formula

Ra	At $\alpha = 15^0$	$0,09756V + 0,33341$
	At $\alpha = 20^0$	$0,002974\,V^2 + 0,33557\,V - 0,09236$
	At $\alpha = 25^0$	$0,34055\,V^2 - 0,71880\,V + 0,87234$

Table 4. Empirical dependences for determining the average value of the depth h of tillage on the speed of the unit V and the α angles of attack of the rings

Parameter	Argument	Calculation formula
h	At $\alpha = 15^0$	$2,1629\,V^2 - 8,8520\,V + 16,6923$
	At $\alpha = 20^0$	$-0,8872\,V^2 + 5,6023\,V + 1,5813$
	At $\alpha = 25^0$	$-1,5338\,V^2 + 8,6445\,V - 0,4775$
	At $V = 1,94\ m/s$	$-0,0012\,\alpha^2 + 0,334\,\alpha + 2,92$
	At $V = 2,77\ m/s$	$0,0032\,\alpha^2 + 0,168\,\alpha + 5,56$
	At $V = 3,33\ m/s$	$0,034\,\alpha^2 - 1,35\alpha + 23,8$

Table 5. Empirical dependences for determining the average value of the degree of weeds destruction Dd on the speed V of tillage unit movement and the corresponding α angles of attack.

Parameter	Argument	Calculation formula
Dd	At $\alpha = 10^0$	$-034,9822\,V^2 + 197,5602\,V - 186,8544$
	At $\alpha = 15^0$	$-14,6937\,V^2 + 75,3791\,V + 1,9927$
	At $V = 1,94\ m/s$	$-0,42\alpha^2 + 16,1\alpha - 54$
	At $V = 2,77\ m/s$	$-0,08\alpha^2 + 3,2\alpha + 68$
	At $V = 3,33\ m/s$	$0,06\alpha^2 - 0,1\alpha + 78$

Table 6. Empirical dependences for determining the average value of the degree of soil crumbling Co on the corresponding α angles of attack of the rings and the speed of tillage unit movement

Parameter	Argument	Calculation formula
Co	At $\alpha = 10^0$	$-121,433V^2 + 575,558V - 568,974$
	At $\alpha = 15^0$	$0,010V^2 + 1,746V + 94,067$
	At $\alpha = 20^0$	$7,36V^2 - 37,761V + 144,092$
	At $\alpha = 25^0$	$-1,722V^2 + 10,529V + 84,041$
	At $V = 1,94\ m/s$	$-0,11\alpha^2 + 4,05\alpha + 61,5$
	At $V = 2,77\ m/s$	$-0,19\alpha^2 + 6,05\alpha + 51$
	At $V = 3,33\ m/s$	$-0,08\alpha^2 + 2,8\alpha + 76$

Analysis of experimental data and dependences of the quality of tillage in figures 7-9 shows that high quality of work is provided at the speed of the tillage machine PM-2/DK V= 2.8-3.3 m/s and the angle of rings installation α=15-22^{o}. At such limits of change in process quality indicators, the traction resistance Ra varies in the range of 0.60-1.26 kN.

Considering the above and the experimental data obtained, the value of the energy intensity of the technological process of pre-sowing tillage of the MTZ-920+ PM-2/DK unit with working elements in the form of rings was determined.

Within the established limits of rational speed modes of operation of the tillage unit V= 2.8-3.3 m/s, high quality of work is provided, the energy intensity of tillage varies within E_i = 373.80-431.18 MJ/ha.

4 Conclusion

The tillage machine performs a number of operations in one pass: pulling out weeds, separating them from the root part, and, accordingly, from the soil, as well as loosening and surface leveling the field during its processing before sowing. Using such a tool with installed rings as working elements allows to increase the degree of loosening of the soil up to 100 %, ensures the destruction of weeds up to 100% and complete leveling of the surface.

The regularities of changes in the agrotechnical and operational indicators of the tillage machine obtained in the course of research can be used in the future in the design and justification of rational modes of operation of aggregates for surface tillage with tractors of various traction classes.

As rational modes of operation of the PM-2/DK tillage machine by the MTZ-920 tractor, the following are set (for conditions of high humidity):

- working speed V= 2.8-3.3 m/s;
- angle of installation of ring working elements α=15-22^{o};
- energy intensity of the technological process E_i = 373.80-431.18 MJ / ha.

A reasonable rational mode of operation of the PM-2/DK tillage machine with MTZ-920 tractor, created with working elements in the form of rings, provides the degree of soil crumbling Co = 100 %, the degree of weeds destruction Dd = 100 %, the depth of tillage h=9-11 cm; as well as the loading of energy means up to $\lambda_p = 0{,}86$ from the nominal mode of tractor operation.

References

1. Yu.F. Lachuga, A.Yu. Izmaylov, Ya.P. Lobachevskiy, N.K. Mazitov, Agricultural Machinery and Technologies, **2**, 37-42 (2017)
2. N.G. Kovalev, A.A. Romanenko, N.K. Mazitov, Agricultural Machinery and Technologies, **1**, 37-41 (2015)
3. S.G. Mudarisov, I.I. Gabitov, Y.P. Lobachevsky, N.K. Mazitov, R.S. Rakhimov, R.R. Khamaletdinov, I.R. Rakhimov, I.M. Farkhutdinov, A.M. Mukhametdinov, R.T. Gareev, Soil & Tillage Research, **190**, 70-77 (2019) DOI.ORG/10.1016/j.still.2018.12.004
4. N.K. Mazitov, B.G. Ziganshin, A.R. Valiev, R.L. Sakhapov, L.Z. Sharafiev, I.R. Rakhimov, Kh.Kh. Shaydullin, M.K. Shaykhov, S.M. Yakhin, F.F. Khisameev, Vestnik of Kazan State Agrarian University, **4(30)**, 65-75 (2013) DOI 10.12737/2912/
5. N.I. Jabborov, A.V. Dobrinov, D.S. Fedkin, Regional Ecology **5,** 23-27 (2015)
6. D.A. Petukhov, Agricultural Machinery and Technologies, **1**, 32-36 (2015)

7. Kristina Lekavičienė, EgidijusŠarauskis, VilmaNaujokienė, SidonaBuragienė, ZitaKriaučiūnienė, Soil and Tillage Research, **192**, 95-102 (2019) https://doi.org/10.1016/j.still.2019.05.002
8. N.I. Dzhabborov, A.V. Dobrinov, V.A. Eviev, *Evaluation of the energy parameters and agrotechnical indicators of aggregate for deep subsurface tillage*, Journal of Physics: Conference Series, 012036, (2019) DOI:10.1088/1742-6596/1210/1/012036
9. N.V. Aldoshin, A.S. Vasiliev, A.V. Kudryavtsev, V.V. Golubev, A.Yu. Alipichev, Agricultural Engineering, **2(96)**, 9-16 (2020) (InEng.) DOI: 10.26897/2687-1149-2020-2-9-16.
10. Iman Ahmadi, Biosystems Engineering, **171**, 52-62 (2018) https://doi.org/10.1016/j.biosystemseng.2018.04.008
11. S.I. Starovoytov, N.P. Starovoytova, N.N. Chemisov, Agricultural Machinery and Technologies, **3,** 30-34 (2014)
12. A.M. Valge, N.I. Jabborov, V.A. Eviev, *Fundamentals of statistical processing of Experimental Data in the Conduct of researches on mechanization of agricultural production with examples on STATGRAPHICS and EXCEL* (St. Petersburg; Elista, Publishing house of the Kalmyk State University, 2015)